Science and Technology Series, Volume 1

New Forests in Eastern Ontario

Hybrid Poplar

Ministry of
Natural
Resources

Ontario

Hon. Alan W. Pope
Minister

W. T. Foster
Deputy Minister

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PREFACE

This is the first publication of a Science and Technology Series dealing with forestry in Ontario. These publications are intended to serve two functions. The first is to provide a comprehensive set of papers that deals with a central theme, of which this publication is an example. The second is to provide individual papers on specific topics that relate to or deal with the work of the Forest Resources Group of the Ministry of Natural Resources.

The papers in this publication have special significance. Not only do they present the summation of accomplishments of studies and practices undertaken during the past five years, but they were presented at a scientific review in August 1981 before a panel of international experts and an audience representing governments, industry, education and the public. A description of the scientific review process and a list of the participants is given in Appendix 1.

Although the program and studies reported here deal primarily with one genus, *Populus*, and have been undertaken in one geographic region in Ontario, the implications and extension of the principles employed have a wide application to other species and areas in the development of intensive forest management practices. The two central components that a forest manager has to deal with and manipulate are the genetic resource of the crop species and the land base. As complete a knowledge of these as possible is required if appropriate management is to be undertaken. Yet it is the interaction between these components and the management practices that is the stuff of forestry, and this can only be judged in the context of management objectives and economic constraints. This context is paramount.

The subjection of the results of this five-year program to a scientific review, in public, illustrates the obligation that scientists and professional resource managers have to place before their peers and the public the results and implications of their work.

K.A. Armson, R.P.F.
Chief Forester

New Forests in Eastern Ontario

Hybrid Poplar

INTRODUCTION

ONTARIO'S HYBRID POPLAR PROGRAM
- AN HISTORICAL PERSPECTIVE

Many current reforestation programs are aimed at satisfying the urgent need to grow trees as quickly as possible. Industrially managed plantation systems are being studied in several countries including Canada in order to satisfy these needs. Silvicultural biomass farms, energy plantations and agri-forestry are some of the names covering the concept of growing large quantitites of tree biomass in the shortest possible time, on accessible sites, by applying intensive management.

Poplars have many of the management and utilization prerequisites for industrial biomass production and in Ontario the work was intiated with this genus. Poplars are among the fastest growing trees in Canada and constitute a significant part of the deciduous timber inventory. In the past, little attention was paid to poplar; recently, however, its significance has increased markedly.

The ease of genetic improvement of poplars by selection, breeding and cloning is of significant advantage. In Canada, as well as in many countries, this advantage attracted breeders. Thus, breeding and a sound approach to the application of its product, laid the foundation of the hybrid poplar program in Ontario.

Tree Breeding Research and Application

In a largely efficiency-minded society, scientific research, technology development and commercial application must follow one another closely. Moreover, this cycle must show continuity. In forest genetics and tree breeding, research and application must also go hand in hand. Thus, the production and the use of genetically improved stock are the two most distinctive aspects of tree breeding.

Breeders must cooperate closely with those who are to use their products and must be prepared for changes. The needs of the wood industry are changing rapidly. Obviously, the breeding of large trees must be different from the breeding of fast-growing hardwoods harvested in one- to three-year cycles and regenerated by stump-sprouts. The tree breeder must try to anticipate some of the future uses of trees. Recent prospects for the use of forest biomass in energy and food production are good examples.

The Role of Breeding in Plantation Management Programs

Breeding has played a leading role in several successful agricultral and forestry programs around the world. Examples of such successes are the programs led by the International Maize and Wheat Improvement Institute (Dr. N. Borlaug) and by the North Carolina State University - Industry Tree Improvement Cooperative (Dr. B. Zobel).

In agriculture, breeding is the backbone of Dr. Borlaug's successful program, which he developed along the lines of cooperative approaches. The program started with breeding. The results, however perfect or imperfect they might have been, were given to other disciplines and to farmers for examination and production trials. The feedback resulted in improved breeding efforts and better production systems, and the continuous interaction kept the program improving and expanding on a worldwide scale.

In forestry, a well known example of success in North America is the southern pine tree improvement program, initiated by Dr. Zobel. It started in the early 1950s through company efforts, by selecting and producing genetically improved seeds for plantations. In less than 30 years the program resulted in greatly improved plantation management and yields, in large areas of fast growing pine plantations and in a new wood industry.

The history of successful eucalyptus and radiata pine plantations is similar. Again, breeders played significant roles in these programs, and cooperation among scientific discipines, research and management was the key to success.

Breeding and Poplar Culture

In some ways, poplar culture also started by breeding. In France in the eighteenth century, hybrid seedlings, resulting from spontaneous crossing between introduced North American eastern cottonwood (*P. deltoides*) and domestic black poplar (*P. nigra*), were selected, propagated and planted. On the basis of these so-called Canadian poplars (*P. canadensis* *syn.* *P.* x *euramericana*), a whole culture has developed.

The introduction of techniques for artifical pollination of poplars in the late 1920s resulted in many new types of hybrids. These, coupled with increased needs for timber and with the spread of pathogens, initiated cooperative reseach efforts in poplar and gave birth to the first Poplar Culture Institute in Casale Monferrato, Italy in 1935. The task of this institute was to breed and select new poplar varieties, to test these for pest resistance, growth and site adaptation, to develop plantation systems for the effective use of the new hybrids, to organize nurseries, distribute stock to producers and to demonstrate the results. Throughout the 1950s and 1960s this institute was the Mecca of poplar culture.

After World War II, the Food and Agriculture Organization of the United Nations established an International Poplar Commission. It assisted greatly in developing expertise, establishing cooperative programs and founding specialized poplar institutions throughout the world.

The Beginning of Poplar Culture in Ontario

In Ontario, poplar breeding was initiated in the mid-1930s by Dr. C. Heimburger and the program was directed by him until his retirement in 1968. Heimburger's breeding laid the groundwork for today's program; in his time, however, poplar breeding met with little support and interest.

In 1969, foresters and wood industries operating in south-eastern Ontario decided that the time and place was right for the initiation of a poplar plantation program in the region. According to estimates, more than 0.5 million hectares of marginal farmland laid idle in the region. Several pulp mills operated in the area and, because of a local shortage, they imported hardwood from Quebec and the USA.

The framework of a poplar plantation management system was put together by the Ontario Ministry of Natural Resources (MNR) and Domtar Incorporated after considering the local means and needs, growth and yield figures from Heimburger's plantations and the use of clones and experience from other countries. Basically, the system involved complete site preparation and tending, the use of plain-cutting planting stock, planting at 3 m by 3 m spacing, 10-year rotation cycles and regeneration by coppice. The objective was the growth of trees approximately 20 cm to 25 cm diameter breast height (DBH) and 18 m to 20 m in height, with approximately 250 m^3/ha of total volume. This goal seemed attainable based on the results of Heimburger's planting trials.

The industry was interested in the pulping quality of the fast-growing poplar. Ten-year-old trees from planting trials were tested and gave satisfactory results.

With government and company support, research and breeding efforts were intensified to create better tree varieties and technologies. In 1971 the Ontario Government formed a Poplar Steering Committee to coordinate research and management efforts. This committee has played a significant role in shaping Ontario's hybrid poplar program.

The Development of a Cooperative Program

It was soon realized that the management of poplar plantations is a complex system, requiring a variety of expertise and solutions.

Identification of sites suitable for poplar was one of the first matters to be addressed. Expertise in site selection and a program of matching clones to sites resulted. Site management and weed control appeared almost insurmountable because most of the abandoned farmland used for poplar planting was in heavy grasses. Many sites were very wet in the spring and not suited for mechanical cultivation until late in the summer when heavy weed competition had already developed. As a result, trials and expertise in chemical weed control were developed.

Disease and insect problems appeared when pests from surrounding natural poplar spread to the poplar plantations. Experts in pathology and entomology helped survey and recognize these pests and provided data for resistance breeding and control.

New ideas for biomass production such as the mini-rotation concept surfaced. Studies of yields, biomass qualities and regeneration by stump resprouting followed.

Studies of biomass led to the examination of the bark-wood-foliage ratio and into the qualities of these biomass components. Research into wood components such as specific gravity, fibres, cellulose-lignin ratio and others followed. Also, the value of wood and foliage for forage was examined and opened new perspectives in utiliztion of forest trees. Finally, studies into energy values and conversion made contributions to the production of poplar biomass for energy.

Studies in many subject areas, ranging from soil nutrients to economics, were undertaken. Thus, extensive cooperation in poplar research has developed. In addition to the Ontario Government's research, several universities and scientists from other agencies participated successfully in this cooperation, which has had neither a formal administrative direction nor central funding. Because of the interest of individual scientists and financial support generated from various funds the cooperation has been very productive.

The Role of Technology Development

Reseach and management began the program jointly and worked well together, but soon the need for a specialized group was realized. Such a group was established in the MNR Brockville District under the administration of the Eastern Region. From 1976 to date, this group of specialists has concentrated on developing technologies for poplar management in the Eastern Region and can take the credit for the achievements in this field. Breeding has played a significant role in the development of Ontario's hybrid poplar culture and the program owes its success to the cooperation developed between research, technology development and management.

New perspectives in genetic engineering give hope for breeding pest-resistant poplars and for developing poplars and plantation systems with nitrogen self sufficiency. The feed values of poplar biomass could result in industries operating to transform this biomass into animal feed and protein concentrates usable by the dairy and meat industries. The energy values of poplar biomass could make great contributions to our society.

Poplars have traditional value as timber and also as shelterbelt and landscape trees. If we add to these uses the new possiblities they offer, we realize that the future of poplar culture in Ontario is great and that we are only at the beginning of the work.

1 THE GENETIC RESOURCE

The quality and diversity of the genetic resource is of paramount consideration to successful forest management. The development of improved genotypes normally leads to improved management.

A greater awareness of management opportunities is created by using genetic stock of superior quality as compared to the known performance of the "normal" or indigenous population. Forest management efforts expended must ensure that the best use is made of high quality genetic material, which may be limited in supply. The resultant silviculture will ensure that full benefits are derived from the utilization of improved genes of known desirable characteristics.

The foundation of the eastern Ontario Hybrid Poplar Program is the diverse, high quality, genetic resource available for intensive forest management. Material from local, national and international gene pools is constantly being acquired and tested to ensure a flow of new and improved genetic stock for culture in eastern Ontario. This is similar to the strategy proposed by Armson and Smith (1978) for the testing of exotic tree species.

This paper will examine the pool of improved hard-wood genes both currently and potentially available for intensive culture in Ontario and will document the preservation and enhancement of the native eastern Ontario gene pool.

Poplars of the World

Since the earliest days of civilization, a large part of man's requirements for wood has traditionally been met by the utilization of poplar (FAO, 1979a). Poplar was obtained from sites that were too wet, rocky or generally unsuitable for agricultural development. Traditionally, poplar was associated with agriculture and is still an integral part of the agricultural economy in present times. The spontaneous breeding of the North American *P. deltoides* Bartr. (eastern cottonwood) with the European *P. nigra* L. (black poplar) in France in the early 1700s began a new era in the culture of poplar. This new culture rapidly expanded throughout the world. Programs investigating the use of an improved *Populus* genetic resource have developed in the northern and, to a limited extent, southern hemispheres. This broad geographic range of programs is directly related to the enormous variation in the number and range of natural species and improved varieties found in the global gene pool. A recent publication (FAO, 1979b) describes the distribution of the *Populus* gene pool of the world.

Both the geneticist and the silviculturist must be aware of the available gene pool, its management and it possible use for future culture. Table 1-1 summarizes the wide range of Populus species.

The climatic requirements of the gene pool must be examined and assessed in conjunction with climatological data for the area where it may be grown. Table 1-2 summarizes the pertinent climatic information for eastern Ontario (Ottawa) and nine major poplar production sites in the world.

Poplars of Eastern Ontario

A large, diverse and improved Populus gene pool has been acquired and is being developed for eastern Ontario. Table 1-3 summarizes the number of new Populus clones introduced into the eastern Ontario field trial and production program since 1972 and illustrates the diversity of the genetic base being used.

By 1981, 388 Populus clones of varying origin and parentage were being tested in the region. Of these, 66 clones have shown exceptional growth potential and have been allocated to regional production plantings. A summary of the clones used for trial and production plantings in the spring of 1981 is presented in Table 1-8 at the end of this chapter.

The eastern Ontario gene pool has gone through three phases of development. Hybrids introduced in the initial stages of the program originated exclusively from traditional European poplar culture. P. x euramericana c.v. 'I-45/51', developed at Casale Monferrato, Italy, was first planted in eastern Ontario in 1972. It is still widely planted on suitable sites in production plantation areas and used as a standard

Table 1-1

Classification of *Populus*

Section	Species	Geographic Distribution
TURANGA Bge	*euphratica* Oliver	W. and C. Asia, N. Africa
	pruinosa Schrenk	C. Asia
LEUCE Duby	*adenopoda* Maxim.	China
	alba L.	Europe, Asia, N. Africa
	davidiana (Dode) Schneid.	N.E. Asia
	grandidentata Michx.	N. America
	sieboldii Miq.	Japan, Korea
	tomentosa Carr.	Asia
	tremula L.	Europe, Asia
	tremuloides Michx.	N. America
LEUCOIDES Spach	*ciliata* Wall	C. Asia
	heterophylla L.	S.E. USA
	lasiocarpa Oliv.	China
	wilsonii Schneid.	China
TACAMAHACA Spach	*angustifolia* James	N. America
	balsamifera L.	N. America
	cathayana Rehd.	N.E. Asia
	koreana Rehd.	Korea
	laurifolia Ledeb.	Siberia
	maximowiczii Henry	N.E. Asia, Japan
	simonii Carr.	Asia
	suaveolens Fisch.	Asia
	szechuanica Schneid.	China
	trichocarpa Hook	N. America
	yunnanensis Dode	China
AIGEIROS Duby	*deltoides* Marsh.	N. America
	fremontii S. Wats.	N. America
	nigra L.	Europe, Asia, N. Africa
	sargentii Dode	N. America
	wislizenii Sarg.	N. America

Source: Zsuffa 1973

clone for comparison in trials. Other early hybrids included 'Regenerata' (DN 16) from France, 'Robusta' (DN 17) from France and 'Negrito de Granada' (DN 31) from Spain.

By 1978, 89 clones were being tested in eastern Ontario, 25 of which were represented in production plantings. During this second phase of development the size of the gene pool rose dramatically but the diversity of clonal material was still limited. Fifty-six per cent of the trial clones and 72 per cent of the production clones were *P.* x *euramericana* hybrids, the majority originating from traditional European poplar culture [e.g., 'Allenstein' (DN 1), 'Baden 431' (DN 2), 'Gelrica' (DN 5), 'Robusta' (DN 10), 'I-214', 'I-65A']. Notable exceptions include three excellent clones with representative Ontario parentage developed by Zsuffa ('DN 55', 'DN 70' and 'JAC 4').

More recently, the diversity of the eastern Ontario *Populus* gene pool has been increased with the import of new and improved breeding material. Many of the hybrids entering the trial program from 1979-81 were developed in Ontario by Zsuffa (see Table 1-8). Trial plantings have indicated the enormous potential of *P.* *nigra* L. x *maximowiczii* Henry crosses for eastern Ontario and most notably of 'NM 1' from Japan, and the 'MAX' clones of West Germany.

During the development of hybrid poplar, studies were initiated with other fast-growing hardwood genera. A fast-growing hardwood, by definition, is a species which, with the appropriate cultural input and when grown on suitable sites, has the capability to yield 10 m^3/ha of wood mean annual increment underbark at rotation (FAO, 1979a). In most instances it is an intolerant, early successional species, capable of rapid

Table 1-1

Classification of *Populus*

Section	Species	Geographic Distribution
TURANGA Bge	*euphratica* Oliver	W. and C. Asia, N. Africa
	pruinosa Schrenk	C. Asia
LEUCE Duby	*adenopoda* Maxim.	China
	alba L.	Europe, Asia, N. Africa
	davidiana (Dode) Schneid.	N.E. Asia
	grandidentata Michx.	N. America
	sieboldii Miq.	Japan, Korea
	tomentosa Carr.	Asia
	tremula L.	Europe, Asia
	tremuloides Michx.	N. America
LEUCOIDES Spach	*ciliata* Wall	C. Asia
	heterophylla L.	S.E. USA
	lasiocarpa Oliv.	China
	wilsonii Schneid.	China
TACAMAHACA Spach	*angustifolia* James	N. America
	balsamifera L.	N. America
	cathayana Rehd.	N.E. Asia
	koreana Rehd.	Korea
	laurifolia Ledeb.	Siberia
	maximowiczii Henry	N.E. Asia, Japan
	simonii Carr.	Asia
	suaveolens Fisch.	Asia
	szechuanica Schneid.	China
	trichocarpa Hook	N. America
	yunnanensis Dode	China
AIGEIROS Duby	*deltoides* Marsh.	N. America
	fremontii S. Wats.	N. America
	nigra L.	Europe, Asia, N. Africa
	sargentii Dode	N. America
	wislizenii Sarg.	N. America

Source: Zsuffa 1973

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Table 1-2

Climatic information for 10 major poplar production sites in the world

Location	Latitude Longitude	Elevation (m)	Average Annual Temp. (°C)	Average Warmest Temp. (°C) (July)	Average Coolest Temp. (°C) (Jan.)	Average Annual High/Low Temp. (°C)	Annual Precipitation (mm) Temp.(°C)	Growing Season (Number of Days Above 5.6°C)	Number of Days of Precipitation During Growing Season
Stoneville, Miss. USA	33°30'N 90°W	38.7	17.8	27.8	6.8	23.9 11.7	1331	222	N/A
Ottawa Canada	45°25'N 75°42'W	87.0	5.3	20.3	-11.1	34.0 -31.0	852	190	65
Milan Italy	45°28'N 9°12'E	121.0	13.7	25.0	2.0	N/A	912	300	74
Quebec City Canada	46°49'N 71°13'W	40.0	4.8	19.8	-11.1	32.0 -31.0	1058	158	78
Seattle USA	47°37'N 122°20'W	3.0	11.8	18.7	5.1	32.0 -6.0	866	270	117
Paris France	48°52'N 2°20'E	60.0	11.1	19.3	3.6	34.0 -9.0	645	240	102
Brussels Belgium	50°50'N 4°20'E	100.0	9.9	17.3	3.2	32.0 -11.0	835	240	88
Kassel W. Germany	51°319N 9°30'E	167.0	9.0	17.9	-0.1	32.0 -14.0	595	250	133
Amsterdam Netherlands	52°23'N 4°54'E	2.0	10.0	17.8	2.8	30.0 -8.0	650	240	128
Stockholm Sweden	59°20'N 18°03'E	44.0	6.6	17.8	-3.1	28.0 -16.0	555	180	51

Source: Brown et al., 1980; Grosvenor, 1975; Putnam et al., 1970; Showers, 1973.

Table 1-3

Populus clones introduced into production and trials in eastern Ontario since 1972

Section	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	Total
Production Clones											
Leuce				2					2		4
Tacamahaca									1		1
Algeiros	1	3	1	4	4	4	1	4	10	11	43
Tacamahaca x Algeiros				1	3	1		1	4	8	18
Total	1	3	1	7	7	5	1	5	17	19	66
Trial Clones											
Leuce				4	1	1	3		35	43	87
Tacamahaca					5					23	28
Algeiros					16	30	4	34	32	67	183
Tacamahaca x Algeiros					19	5	1	16	23	26	90
Total				4	41	36	8	50	90	159	388

Values are for numbers of new clones per year.

juvenile growth, which has the ability to respond to improved site conditions.

Table 1-4 summarizes the range of fast-growing hardwood species represented in trial plantings in the region. The objective of securing populations and clones of species that have potential for eastern Ontario culture is twofold:

- To investigate potential fast-growing species on sites not well suited to Populus.
- To identify genes with the potential for future improvement.

The fast-growing hardwood genera which appear to have potential for eastern Ontario culture are: Ailanthus, Alnus, Betula, Carya, Castanea, Catalpa, Fraxinus, Gleditsia, Liquidambar, Liriodendron, Nothofagus, Nyssa, Paulownia, Populus, Robinia, Salix, Sassafras and Ulmus.

Particular emphasis is now placed on the preservation and enhancement of the native poplar gene pool. The poplar tree is usually the largest tree in the eastern Ontario forest, and, as such, is usually the first to be cut when the forest is exploited. With increasing pressures on the natural forest to supply the region's wood fibre and energy needs, there is an even greater pressure on the native poplar gene pool. Of the 66 clones in production (Table 1-3) there are no clones with eastern Ontario parentage. There is an urgency, therefore, to preserve a rapidly disappearing native poplar gene pool for use in the future breeding program.

A selection program was initiated in 1979 to identify and preserve the native poplar gene pool. Four native Populus species - P. tremuloides Michx. (trembling aspen), P. grandidentata Michx. (largetooth aspen), P. balsamifera L. (balsam poplar) and P. deltoides Bartr. (eastern cottonwood) are being selected throughout the region. After selection, propagating material is collected from each selected tree, propagated at the G. Howard Ferguson (Kemptville) Nursery and preserved in a clonal archive (seed orchard) area. At the inception of this program in 1979, eastern Ontario was divided into 110 selection cells, each cell consisting of one township. Within each cell, a target

Table 1-4

Summary of fast-growing hardwoods gene pool as of 1981

Species	Number of Populations/Clone
Alnus spp (12 species)	
cordata	3
cremastogyne	1
glutinosa	34
incana	5
japonica	1
maximowiczii	1
rubra	8
rugosa	2
sinuata	3
tenuifolia	1
trabeculosa	1
viridis	1
Total	61
Betula spp (7 species)	
occidentalis	2
papyrifera	3
pendula	3
platyphylla	1
populifolia	3
pubescens	5
verrucosa	12
Total	29
Salix species	56 (clones)
Other F.G.H. species	
Nothofagus (6 species)	8
Ailanthus altissima	1
Catalpa speciosa	1
Gleditsia triacanthos	1
Liquidambar styraciflua	1
Liriodendron tulipfera	2
Paulownia tomentosa	1
Robinia pseudoacacia	4
Sassafras albidum	1
Total	20

of one selection per species was set. Table 1-5 summarizes the Populus selections made in 1979 and 1980. Figures 1-1 to 1-4 outline the spatial distribution of the selections, by species, made to date in eastern Ontario. The following distribution trends should be noted:

- A strong correlation exists between the northern limit of the P. deltoides selections and a line delineating 3200 mean annual growing degree days (Brown et al., 1980). (Mean annual growing degree days is defined as the accumulated annual value of the number of degrees Fahrenheit of mean daily temperature above a base of 5.6 C.) This trend corroborates the northern range of P. deltoides as documented by Maini (1968).

Table 1-5

Populus gene pool selections made in eastern Ontario for 1979 and 1980

	Number of Selections	
Species	1979	1980
P. tremuloides	52	68
P. grandidentata	52	70
P. balsamifera	95	99
P. deltoides	104	94
Total	303	331

- The limited number of selections of P. tremuloides, P. grandidentata and P. balsamifera in many areas along the St. Lawrence River and Lake Ontario is related to several factors, one of which may be the effect of the pressure of man's wood requirements on the native poplar resource.

Although tree appearance does not expose all the desirable or undesirable genetic qualities of an individual, the best phenotypic selection in an area is usually genetically superior (Van Haverbeke, 1976). Therefore, within each selection cell, the most promising phenotype of each species is identified. Selection of a particular tree is based on a series of attributes which are:

- Tree form (e.g., bole straightness; angle, density and thickness of branches)
- Vigour (including leader growth and diameter increment)
- Health (frost hardiness, freedom from insects and disease)
- Location (site)
- Abundance of species within the cell

A comprehensive documentation of the characteristics of the selected tree and site is made.

In the fall and winter after tree selections have been made, branch and root propagating material are collected from each tree. Roots are collected from

Figure 1-1

Locations of *P. tremuloides* selections in eastern Ontario (1979-80)

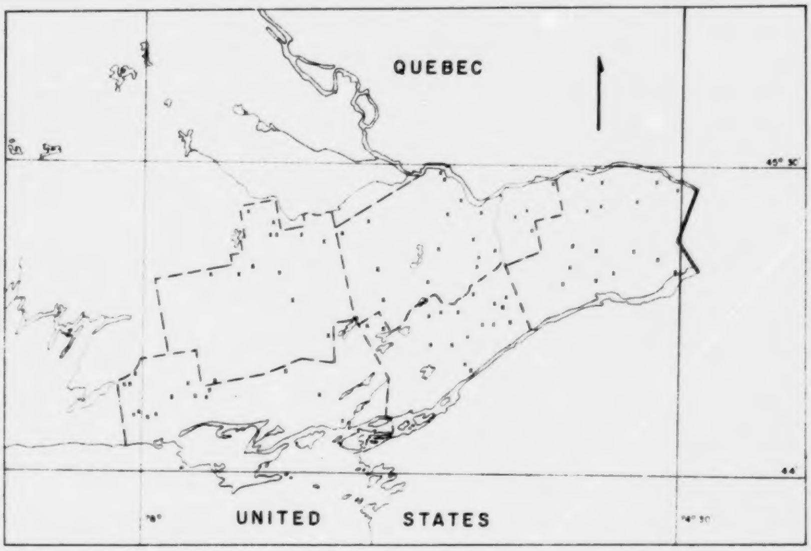

QUEBEC
45° 30'
44°
UNITED
STATES
74° 30'

Figure 1-2

Locations of *P. grandidentata* selections in eastern Ontario (1979-80)

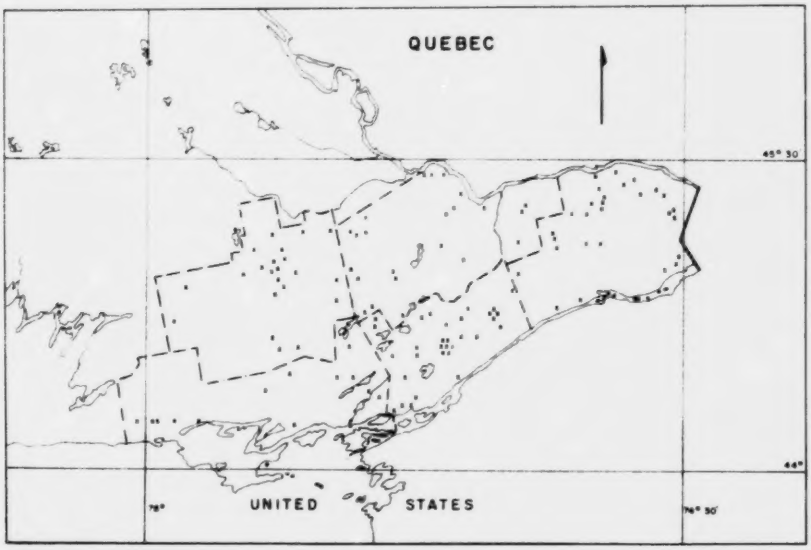

QUEBEC
45° 30'
44°
UNITED
STATES
74° 30'

Figure 1-3

Locations of *P. balsamifera* selections
in eastern Ontario (1979-80)

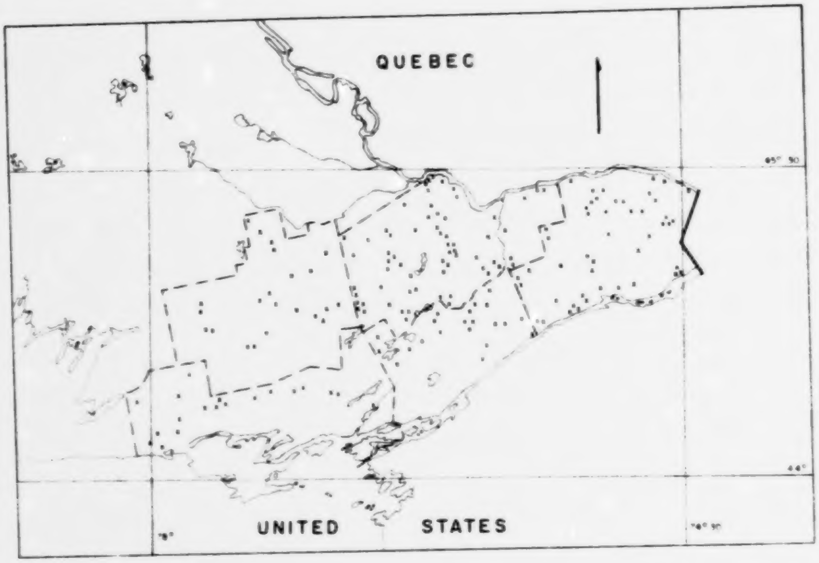
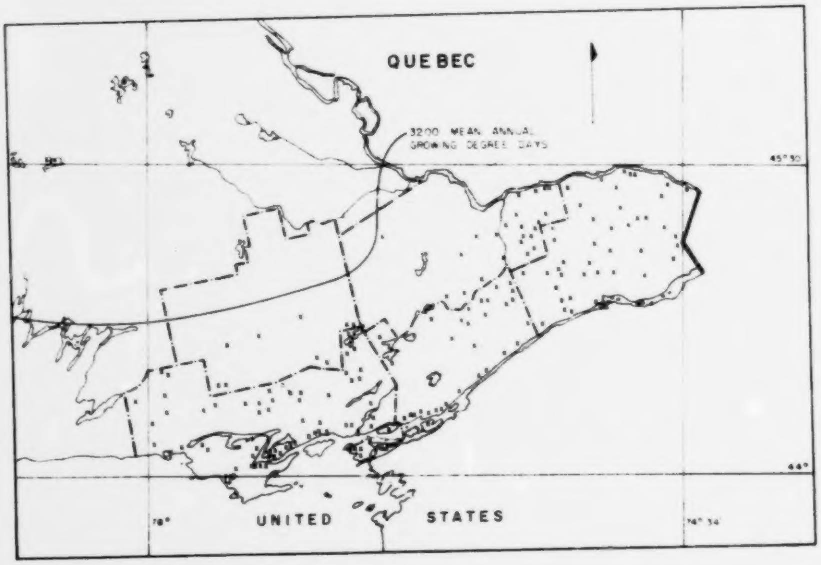

QUEBEC
45° 30
44°
78°
UNITED
STATES
74° 30

Figure 1-4

Locations of *P. deltoides* selections
in eastern Ontario (1979-80)


QUEBEC
3200 MEAN ANNUAL
GROWING DEGREE DAYS
45° 30
44°
78°
UNITED
STATES
74° 34'

P. tremuloides, P. grandidentata and P. balsamifera and branches are collected from all species. This material is delivered to the Kemptville Nursery where it is propagated in a greenhouse. The propagules are outplanted in a clonal archive area in the spring. The propagation procedures and establishment of the clonal archive are described in Chapter 5. The clonal archive represents a microcosm of poplar from eastern Ontario and will serve as a reservoir of genetically valuable material for the future breeding program.

Selection is the first step in exploiting genetic variation but must be followed by progeny testing to attain the maximum genetic gains (Van Haverbeke, 1976). After gene pool selections are made, the gene pool is recombined through a detailed breeding program to produce progeny. The progeny are tested in specially prepared areas and monitored to identify those valuable for future breeding. Selections are normally made when the individuals are five years old. The elite trees (trees of proven good combining ability [Wright, 1976]) are then established and preserved in a separate gene archive. The elite trees may be used either as clonal stock for test in eastern Ontario or for future breeding with exotics.

Several hundred full-sib families (both parents in common [Wright, 1976]) have been produced (Table 1-6) and Figure 1-5 outlines the operational-scale breeding techniques which are being employed to produce full-sib seed for future progeny testing.

Flower branches are collected after the first week of January. In the past, branches collected before January were found to be variable in the degree of bud and subsequent flower development. The breeding scheme is prepared prior to the actual greenhouse breeding

breeding operations. Table 1-7 outlines the species crosses that are used in the program. Crosses between Leuce section (i.e., the aspens) and the Aigeiros and Tacamahaca sections are not considered because of the low success and unsatisfactory results to be expected as reported by Zsuffa (1973), and Guries and Stettler (1978). The breeding scheme is based on defining discrete populations and crossing both between and within populations and species. Populations are defined by first identifying a northern and southern population based on mean annual growing degree days and by using physiographic information to define a limestone versus Canadian shield (granite) population. A minimum of three random crosses for each female is made.

All male flower branches are placed in water in separate rooms to ensure that contamination of the pollen source does not occur. The pollen is refrigerated at 2°C immediately after collection to preserve maximum pollen viability.

Table 1-6

Breeding output for an operational scale breeding program, 1979 and 1980

Cross				
Female	Male	1979	1980	Total
Leuce	Leuce	17	50	67
Tacamahaca	Tacamahaca	30	15	45
Aigeiros	Aigeiros	37	25	62
Tacamahaca	Aigeiros	1	3	4
Aigeiros	Tacamahaca	2	7	9
Total		87	100	187

Values are for number of successful crosses

Bottle grafting is used for *P. balsamifera* and *P. deltoides*, to bring about successful flowering and seed maturation of the female flower branch. The grafted flower branches are placed in a temperature-controlled greenhouse (day:night temperatures 20°C:15°C).

Just prior to a flower branch entering the receptive stage, a plastic cage is placed over the bottle graft to avoid contamination when pollination is done. The procedure for aspen breeding differs only in that bottle grafts are not required for aspen breeding. Branches placed in water will flower successfully and develop seed through to maturity. The seed is collected at maturity, sifted from the cotton by a screening device and then stored at 4°C until required for the propagation of seedlings.

In conjunction with the production of full-sib seed from controlled breeding, half-sib seed (one parent in common [Wright, 1976]) is collected from open-pollinated female selections in the spring.

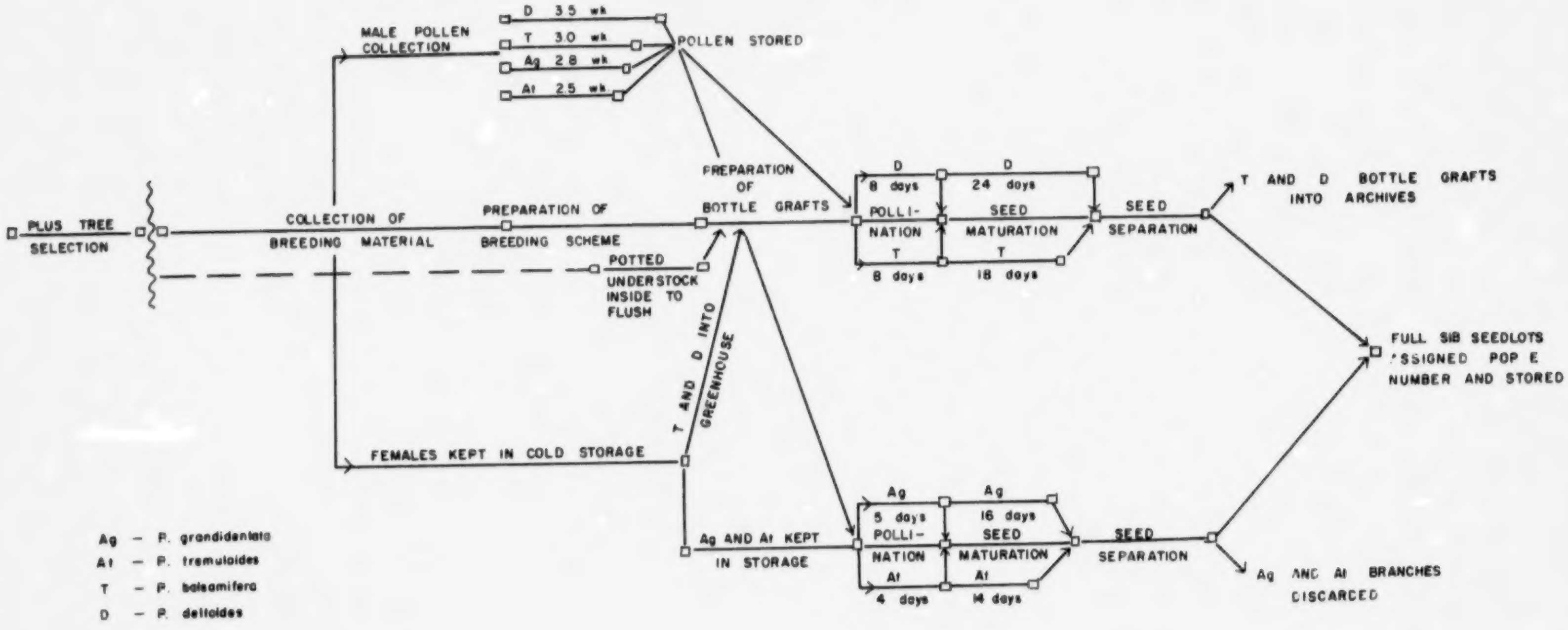
Table 1-7

Species crosses for breeding native *Populus* gene pool

Section	Male	Female
Leuce	*P. tremuloides*	*P. tremuloides*
	P. grandidentata	*P. grandidentata*
Tacamahaca	*P. balsamifera*	*P. balsamifera*
Aigeiros	*P. deltoides*	*P. deltoides*
Aigeiros x Tacamahaca	*P. deltoides* *P. balsamifera*	*P. balsamifera* *P. deltoides*

Figure 1-5

Operational scale poplar breeding program, 1980


PLUS TREE SELECTION
COLLECTION OF BREEDING MATERIAL
MALE POLLEN COLLECTION
D 3.5 wk
T 3.0 wk
Ag 2.8 wk
At 2.5 wk
POLLEN STORED
PREPARATION OF BREEDING SCHEME
PREPARATION OF BOTTLE GRAFTS
POTTED UNDERSTOCK INSIDE TO FLUSH
FEMALES KEPT IN COLD STORAGE
T AND D INTO GREENHOUSE
Ag AND At KEPT IN STORAGE
D
8 days
POLLI- NATION
T
8 days
D
24 days
SEED MATURATION
T
18 days
SEED SEPARATION
T AND D BOTTLE GRAFTS INTO ARCHIVES
FULL SIB SEEDLOTS ASSIGNED POP E NUMBER AND STORED
Ag
5 days
POLLI- NATION
At
4 days
Ag
16 days
SEED MATURATION
At
14 days
SEED SEPARATION
Ag AND At BRANCHES DISCARDED
Ag — P. grandidentata
At — P. tremuloides
T — P. balsamifera
D — P. deltoides

The Question of Diversity

Much insight can be gained from examining the history of wheat breeding for rust resistance. The wheat gene pool of the world has been refined from one strain after another, none of which could exist without man and each e succumbing to destruction by pest infestation (Silen, 1976). A new resistant strain under observation, "in th wings" so to speak, is periodically brought into culture drawn from an original gene pool derived from a few acre in the Mediterranean area.

The wide diversity of the Populus gene pool contrasts with that of wheat. The more critical question to pose in view of the wheat analogy is how much gene pool diversity should a manager keep in the wings, and subsequently, what level of diversity should be considered to efficiently utilize the available gene pool.

With reference to the wheat analogy, new and improved wheat strains replace old strains every five years or less to maintain a level of resistance ahead of the rust. In the same manner, as new and improved Populus genetic material is transferred by the geneticist to the silviculturist, older clones may be removed from the production system.

Pests have caused the demise of plantations and programs which were based on a limited genetic base. In eastern Ontario potential pest problems are minimized in several ways.

1. Plantations are established using objective data to match the most suitable clone to each particular site.
2. Each selected site must be capable of supporting rapid tree growth.

3. The sites are planted with several, rather than one or two clones.
4. Each clone does not occupy more than five hectares of the total plantation area and, as in the natural poplar forest, clonal blocks are only one to two hectares in size, thereby localizing pest problems.
5. Each clone being tested, or in production, is monitored for insect and disease susceptibility. Susceptible clones are removed from production planting as more reliable, resistant clones are utilized.

As indicated in Table 1-3, the eastern Ontario program supports a very diverse genetic resource base. A large genetic diversity is the insurance policy for successful future culture. The wide range of soils and sites in eastern Ontario can support the development of a widely diverse gene pool material. By objectively testing a large number of clones on each particular site, rather than testing a few select individuals, more planting options are available for the site, with equal or greater gains in yield.

Table 1-8

Summary of clones in trial and production allocation in eastern Ontario, spring 1981

Section: Leuce

Ontario Code	Species or Hybrid	Clonal No. or Cultivar Name	Country of Origin
A 487	P. alba var. 'Bachofenii'		U.S.S.R.
A 499	P. alba	'I-57/57'	Italy
A 502	P. alba	'I-58/57'	Italy
AK 28	P. alba x glandulosa		Ontario, Canada
AK 30	P. alba x glandulosa		Ontario, Canada
AK 41	P. alba x glandulosa		Ontario, Canada
AK 50	P. alba x glandulosa		Ontario, Canada
AK 61	P. alba x glandulosa		South Korea
AG 186	P. alba x grandidentata	'Hansen'	Iowa, USA
AG 212	P. alba x grandidentata		Ontario, Canada
AS 31	P. alba x sieboldii		Ontario, Canada
AS 34	P. alba x sieboldii		Canada
C 147	P. x canescens		West Germany
C 180	P. x canescens	'Pyramidalis'	Yugoslavia
CAG 54	P. x canescens x alba x grandidentata		Ontario, Canada
CAG 204	P. x canescens x alba x grandidentata		Ontario, Canada
GA 88	P. grandidentata x alba		Ontario, Canada
GA 91	P. grandidentata x alba		Ontario, Canada

Section: Aigeiros and Tacamahaca

Ontario Code	Species or Hybrid	Clonal No. or Cultivar Name	Country of Origin
D 37	*P. deltoides*	W-1-4	Ontario, Canada
D 38	*P. deltoides*		Ontario, Canada
D 51	*P. deltoides*	F9	Manitoba, Canada
D 68	*P. deltoides*		Indiana, USA
D 74	*P. deltoides*		Michigan, USA
D 87	*P. deltoides*	'Lydick'	Kansas, USA
D 189	*P. deltoides*	'Brooks #1'	Alberta, Canada
D 195	*P. deltoides*	'Walker'	Saskatchewan, Canada
D 198	*P. deltoides*	'Angustifolia'	Saskatchewan, Canada
DN 1	*P.* × *euramericana*	'Allenstein'	West Germany
DN 2	*P.* × *euramericana*	'Baden 431'	West Germany
DN 3	*P.* × *euramericana*	'Dolomiten'	West Germany
DN 5	*P.* × *euramericana*	'Gelrica'	West Germany
DN 7	*P.* × *euramericana*	'Heidemij'	West Germany
DN 9	*P.* × *euramericana*	'Lons'	West Germany
DN 10	*P.* × *euramericana*	'Robusta'	West Germany
DN 14	*P.* × *euramericana*	'Harff'	West Germany
DN 15	*P.* × *euramericana*	'Regenere d'Aube'	France
DN 16	*P.* × *euramericana*	'Regenere Batard d'Hauterive'	France

Section: Aigeiros and Tacamahaca

Ontario Code	Species or Hybrid	Clonal No. or Cultivar Name	Country of Origin
DN 17	*P.* x *euramericana*	'Robusta'	France
DN 18	*P.* x *euramericana*	'Tardif de Champagne'	France
DN 19	*P.* x *euramericana*	'Blanc du Poitou'	France
DN 20	*P.* x *euramericana*	'I-61/59'	Italy
DN 21	*P.* x *euramericana*	'Tacometti 78B'	Italy
DN 22	*P.* x *euramericana*	'I-262'	Italy
DN 25	*P.* x *euramericana*	'I-55/56'	Italy
DN 28	*P.* x *euramericana*	'Ostia'	West Germany
DN 30	*P.* x *euramericana*	'Canada Blanc'	Spain
DN 31	*P.* x *euramericana*	'Negrito de Granada'	Spain
DN 33	*P. deltoides*	'Virginie de Nancy'	France
DN 36	*P. angulata* x *plantierensis*		New Hampshire, USA
DN 38	*P. deltoides* v.'Virginiana' x 'Volga Poplar' 'NE-238'		New Hampshire, USA
DN 52	*P.* x *euramericana*		Quebec, Canada
DN 55	*P. deltoides* x *nigra*		Ontario x Canada
DN 65	*P. deltoides* x *nigra*		Ontario, Canada
DN 66	*P. deltoides* x *nigra*		Ontario, Canada
DN 69	*P. deltoides* x *nigra*		Ontario, Canada
DN 70	*P. deltoides* x *nigra*		Ontario, Canada
DN 74	*P. deltoides* x *nigra*		Ontario, Canada
DN 76	*P. deltoides* x *nigra*		Ontario, Canada
DN 77	*P. deltoides* x *nigra*		Ontario, Canada
DN 90	*P. nigra*	'VB-8'	Yugoslavia
DN 93	*P.* x *euramericana*	'I-37/61'	Italy
DN 96	*P. deltoides* x *nigra*		
DN 101	*P. deltoides* x *nigra*		Ontario, Canada
DN 102	*P. deltoides* x *nigra*		Ontario, Canada
DN 103	*P. deltoides* x *nigra*		
DN 104	*P. deltoides* x *nigra*		

Section: Aigeiros and Tacamahaca

Ontario Code	Species or Hybrid	Clonal No. or Cultivar Name	Country of Origin
DN 106	*P. deltoides* × *nigra*		Ontario, Canada
DN 107	*P. deltoides* × *nigra*		Ontario, Canada
DN 110	*P. deltoides* × *nigra*		Ontario, Canada
DN 112	*P. deltoides* × *nigra*		Ontario, Canada
DN 113	*P. deltoides* × *nigra*		Ontario, Canada
DN 114	*P. deltoides* × *nigra*		Ontario, Canada
DN 116	*P. deltoides* × *nigra*		Ontario, Canada
DN 123	*P. deltoides* × *nigra*		Ontario, Canada
DN 125	*P. deltoides* × *nigra*		Ontario, Canada
DN 128	*P. deltoides* × *nigra*		Ontario, Canada
DN 131	*P. deltoides* × *nigra*		Ontario, Canada
DN 132	*P. deltoides* × *nigra*		Ontario, Canada
DN 133	*P. deltoides* × *nigra*		Ontario, Canada
DN 134	*P. deltoides* × *nigra*		Ontario, Canada
DN 136	*P. deltoides* × *nigra*		Ontario, Canada
DN 138	*P. deltoides* × *nigra*		Ontario, Canada
DN 144	*P. deltoides* × *nigra*		Ontario, Canada
DN 145	*P. deltoides* × *nigra*		Ontario, Canada
DN 149	*P. deltoides* × *nigra*		Ontario, Canada
DN 152	*P. deltoides* × *nigra*		Ontario, Canada
DN 157	*P. deltoides* × *nigra*		Ontario, Canada
DN 159	*P. deltoides* × *nigra*		Ontario, Canada
DN 160	*P. deltoides* × *nigra*		Ontario, Canada
DN 170	*P. deltoides* × *nigra*		Ontario, Canada
DN 173	*P.* × *euramericana*	'Dorskamp'	Netherlands
DN 174	*P.* × *euramericana*	'Flevo'	Netherlands
DN 175	*P.* × *euramericana*	'Spijk' (1775)	Netherlands
DN 177	*P.* × *euramericana*	'Spijk' (1776)	Netherlands
DN 178	*P.* × *euramericana*	'Spijk' (2195)	Netherlands
DN 181	*P.* × *euramericana*	'Drapal Wulst'	West Germany
DN 182	*P.* × *euramericana*	'Raverdeau'	
DN 184	*P. deltoides* × *nigra* V. *caudina*	Quebec No.52	New Hampshire, USA
DN 185	*P.* × *euramericana*	'Maine Robusta'	New Hampshire, USA
I-45/51	*P.* × *euramericana*	'I-45/51'	Italy

Section: Aigeiros and Tacamahaca

Ontario Code	Species or Hybrid	Clonal No. or Cultivar Name	Country of Origin
I-65A	*P.* x *euramericana*	'I-65A'	Farnham, England
JAC 34	*P. maximowiczii* x *trichocarpa*	'NE 388'	New Hampshire, USA
NE 41	*P. maximowiczii* x *trichocarpa*	'Androscoggin'	New Hampshire, USA
NE 308	*P. nigra* 'Charkowiensis' x *nigra* 'Incrassata'	'NE 308'	New Hampshire, USA
TRICH 15	*P. trichocarpa*	'267/63(14)'	West Germany
TRICH 16	*P. trichocarpa*	'267/63(6)'	West Germany
TRICH 17	*P. trichocarpa*	'Weser 3'	West Germany
TRICH 18	*P. trichocarpa*	'Weser 8'	West Germany
TRICH 19	*P. trichocarpa*	'Muhle-Larsen'	West Germany
TRICH 20	*P. trichocarpa*	'Scott Pauley'	West Germany
TRICH 21	*P. trichocarpa*	'BRUHL-1'	West Germany
TRICH 22	*P. trichocarpa*	'BRUHL-2'	West Germany
TRICH 23	*P. trichocarpa*	'BRUHL-3'	West Germany
TRICH 24	*P. trichocarpa*	'BRUHL-4'	West Germany
TRICH 27	*P. trichocarpa*	'BRUHL-7'	West Germany
Z 1	*P.* x *euramericana*	'Spreewaldpapper'	East Germany
Z 13	*P. angulata*		Ontario, Canada
Z 28	*P.* x *euramericana*	'Leipzig'(B177)	Holland

Cross: Aigeiros x Tacamahaca

Ontario Code	Species or Hybrid	Clonal No. or Cultivar Name	Country of Origin
DTAC 16	*P. angulata* x *trichocarpa*	Quebec No.6	New Hampshire, USA
DTAC 17	*P. angulata* x *trichocarpa*	Quebec No.10	New Hampshire, USA
DTAC 18	*P. angulata* x *trichocarpa*	Quebec No.34	New Hampshire, USA
DTAC 19	*P. angulata* x *trichocarpa*	Quebec No.51	New Hampshire, USA
DTAC 23	*P. angulata* x *trichocarpa*	'NE 255'	New Hampshire, USA
DTAC 32	*P. angulata* x *trichocarpa*		New Hampshire, USA
DTAC 4	*P. deltoides* x *trichocarpa*		Ontario, Canada
DTAC 7	*P. deltoides* x *trichocarpa*	'S910-1'	Belgium
DTAC 8	*P. deltoides* x *trichocarpa*	'S910-2'	Belgium
DTAC 9	*P. deltoides* x *trichocarpa*	'Donk'(1647)	Netherlands
DTAC 11	*P. deltoides* x *trichocarpa*	'Barn'(1623)	Netherlands
DTAC 12	*P. deltoides* x *trichocarpa*	'Barn'(1621)	Netherlands
DTAC 15	*P. deltoides* x *trichocarpa*	'NE 207'	New Hampshire, USA
DTAC 20	*P. deltoides* x *trichocarpa*	Quebec No.33	New Hampshire, USA
DTAC 26	*P. deltoides* x *trichocarpa*	'S910-8'	Belgium
DTAC 27	*P. deltoides* x *trichocarpa*	'Unal 7'	Belgium
DTAC 29	*P. deltoides* x *trichocarpa*	'S910-10'	Belgium
NE 10	*P. nigra* x *trichocarpa*	'NE 10'	New Hampshire, USA
NM 1	*P. nigra* x *maximowiczii*		Japan
NM 2	*P. nigra* x *maximowiczii*	'MAX-1'	West Germany
NM 3	*P. nigra* x *maximowiczii*	'MAX-2'	West Germany
NM 4	*P. nigra* x *maximowiczii*	'MAX-3'	West Germany
NM 5	*P. nigra* x *maximowiczii*	'MAX-4'	West Germany

Cross: Tacamahaca x Aigeiros

Ontario Code	Species or Hybrid	Clonal No. or Cultivar Name	Country of Origin
JAC 4	*P.* x *jackii*		Ontario, Canada
JAC 16	*P.* x *jackii*		Newfoundland, Canada
JAC 23	*P.* x *jackii*		Quebec, Canada
MD 1	*P.* *maximowiczii* x *deltoides*		Japan
NE 52	*P.* *maximowiczii* x *plantierensis*	'NE 52'	New Hampshire, USA
JACN 1	*P.* x *jackii* x *nigra*		Ontario, Canada
JAC 31	*P.* *deltoides*	FII	Manitoba, Canada
DTAC N 1	*P.* *candicans* x *berolinensis*	Quebec No.29	New Hampshire, USA
OP 45	*P.* *maximowiczii* x *berolinensis*		New Hampshire, USA
JACN 5	*P.* x *jackii* x *nigra*		Ontario, Canada
JACN 12	*P.* x *jackii* x *nigra*		Ontario, Canada
JACN 16	*P.* x *jackii* x *nigra*		Ontario, Canada
JACN 18	*P.* x *jackii* x *nigra*		Ontario, Canada
JACN 23	*P.* x *jackii* x *nigra*		Ontario, Canada

Cross: Aigeiros x Tacamahaca x Aigeiros

Ontario Code	Species or Hybrid	Clonal No. or Cultivar Name	Country of Origin
DTAC 1	*P. angulata* x *berolinensis*		Wisconsin, USA
DTAC 2	*P. angulata* x *berolinensis*		Wisconsin, USA
8/33A	*P. generosa* x *serotina*	'8/33'	Austria
IE 33	*P. generosa* x *jackii*	'IE33'	USA
IE 34	*P. generosa* x *jackii*	'IE35'	USA
3B 23	*P. generosa* x *jackii*	'3B23'	USA
3C 29	*P. generosa* x *jackii*	'3C29'	USA

2 GROWTH, DENSITY AND TIME

In this chapter, plant density and rotation age are considered to define a management system. A wide range of management systems can be characterized through the study of growth in relation to density and time. The Nelder spacing design (Nelder, 1962) provides a convenient means to study these relationships on an individual tree basis.

The relationships between growth, density and time for Populus x euramericana (Dode) Guinier cv.'DN 17' (Robusta) on two contrasting sites are presented. Management systems are also projected and the technology discussed.

Randomized block designs have traditionally been used in forestry spacing studies and the effect of initial spacing on yield per unit area has been the primary objective of such studies. This approach requires a relatively large experimental area, necessitated by the requirement for buffer trees and the need for large plot size to accommodate the wider spacings. A randomized block experiment either has a standard plot size with an unequal number of trees per plot or vice versa. Both options provide analytical complications.

Nelder's designs were originally intended for vegetable crops and were adapted to forestry purposes by Van Slyke (1964).

Methods

Twenty-five Nelder plots have been established since 1976 over a broad range of sites using a limited number of production clones. These plots were set out in conjunction with production plantations and clone-site trials. The results from two Nelders established on contrasting sites using *P.* x *euramericana* cv. 'DN 17' are given for a four-year period. The soil at Grenville 32 (G-32) is a moderately well drained sandy loam. At Domtar 8 (D-8) the plot is located on an imperfectly drained loam.

Figure 2-1 shows a Nelder plot and Table 2-1 gives the area per tree and density (trees/hectare) for the Nelders used. Trees are planted along each radius, their spacing determined in a systematic fashion, with the closest spacings near the centre and the widest spacings towards the outside of the wheel.

The Nelder design provides the opportunity to assess the change in tree characteristics with changes in the growing space per tree. A single Nelder plot does not provide for an estimate of the variance caused by site variation; this problem will be dealt with later.

Figure 2-1

The Nelder design

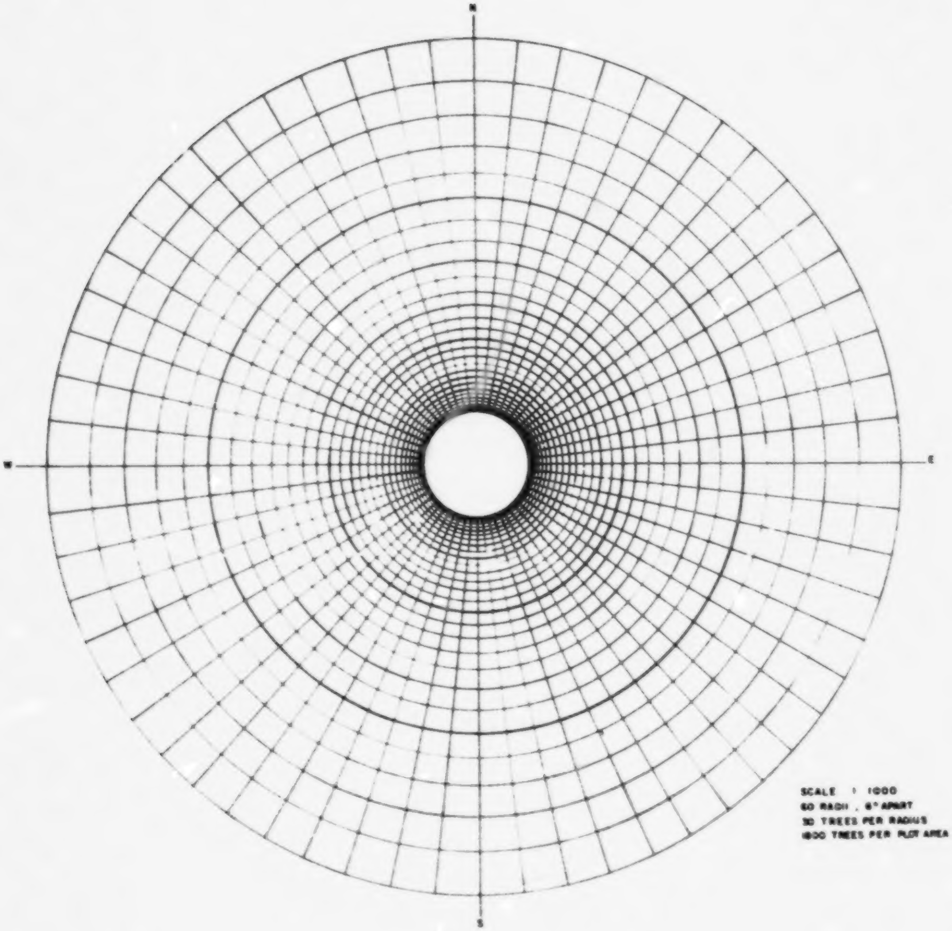

N
W
E
S
SCALE 1 1000
60 RADII , 6° APART
30 TREES PER RADIUS
1800 TREES PER PLOT AREA

Table 2-1

The Nelder design

	Nelder Spacing	
Arc	Area/Tree (m^2)	Trees/ha
1	.29	35,564
2	.35	28,572
3	.43	23,241
4	.53	18,956
5	.64	15,616
6	.78	12,744
7	.96	10,446
8	1.17	8,557
9	1.43	7,013
10	1.74	5,755
11	2.12	4,714
12	2.60	3,846
13	3.17	3,150
14	3.87	2,583
15	4.73	2,112
16	5.77	1,732
17	7.05	1,419
18	8.60	1,163
19	10.51	951
20	12.84	779

Results

Growth in Relation to Density by Time

Regressions of diameter per tree versus area per tree are presented in Table 2-2. The Domtar 8 measurements have been given for breast height while the Grenville 32 measurements are for stump height. Comparable data is available for year four and this will be used to compare regression lines of the two sites later in the paper. The initial regressions in Table 2-2 are illustrated in Figures 2-2 and 2-3 where $\hat{y}$ is the diameter (cm) and x is the area per tree (m^2). All r^2 values are very significant (P=0.01). This is a reflection of the fact that diameter is strongly affected by density. Similar regressions were prepared for height and are shown in Table 2-3 and Figures 2-4 and 2-5, where the dependant variable is the height (cm) and the independent variable is the area per tree (m^2).

The lack of correlation on G-32 is the result of poor initial weed control and variation of site.

Growth measured by basal area by height was plotted against area per tree for each of years two, three and four. Curvilinear regressions based on these data were calculated and are shown in Figures 2-6 and 2-7 and are summarized in Table 2-4. Each average is based on 60 trees (the number of radii in each Nelder) unless, due to mortality, a lesser number was available.

All r^2 values are very significant (P = 0.01). The better fit of Domtar 8 data is the result of very high survival. The variation on Grenville 32 is primarily the result of problems with weed control during early years of the Nelder and variation in site conditions. It should be noted that basal area times

Table 2-2

Regressions relating diameter growth (Y) to area per tree (X) for two Nelder plots

Domtar 8			Grenville 32	
Year 2	$Y = 2.769\ X^{.243}$	$r^2 = 0.985$	Not available	
Year 3	$Y = 2.057\ x^{.218}$	$r^2 = 0.973$	$Y = 3.771\ x^{.194}$	$r^2 = 0.924$
Year 4	$Y = 1.188\ x^{.161}$	$r^2 = 0.938$	$Y = 4.690\ x^{.213}$	$r^2 = 0.902$

Table 2-3

Regressions relating height growth (Y) to area per tree (X)(m^2) for two Nelder plots

Domtar 8			Grenville 32
Year 2	$Y = 237.279\ x^{.090}$	$r^2 = 0.974$	No correlation
Year 3	$Y = 359.036\ x^{.109}$	$r^2 = 0.960$	No correlation
Year 4	$Y = 460.074\ x^{.48}$	$r^2 = .901$	No correlation

Table 2-4

Regressions of basal area x height (Y) plotted against area/tree (X)(m^2) for two Nelder plots

Domtar 8			Grenville 32	
Year 2	$Y = 263.209\ x^{.412}$	$r^2 = 0.936$	Not available	
Year 3	$Y = 11193.186\ x^{.545}$	$r^2 = 0.972$	$Y = 4624.408\ X^{.418}$	$r^2 = .898$
Year 4	$Y = 2771.212\ x^{.605}$	$r^2=0.983$	$Y = 9634.395\ X^{.466}$	$r^2 = .866$

Note: For Domtar 8, basal area values were based on diameter at breast height. Grenville 32 basal areas were based on diameter at stumip height.

Figure 2-2

Growth/density by time for diameter at breast height, Domtar 8

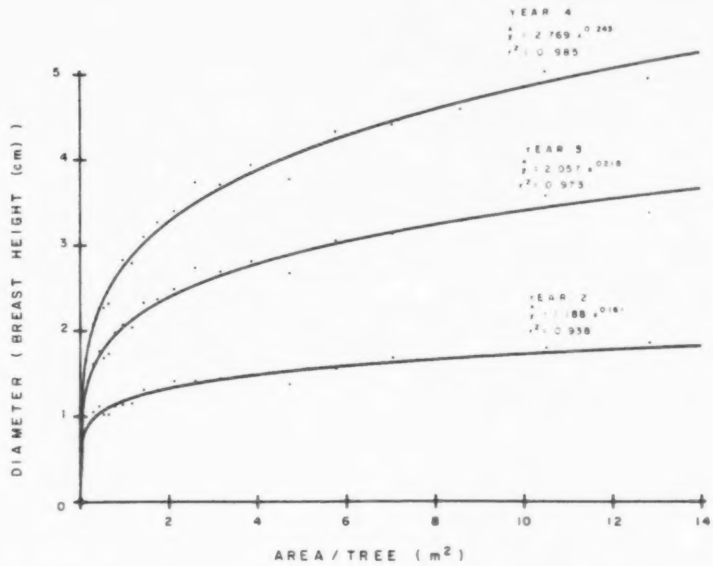


Figure 2-3

Growth/density by time for diameter at stump height, Grenville 32

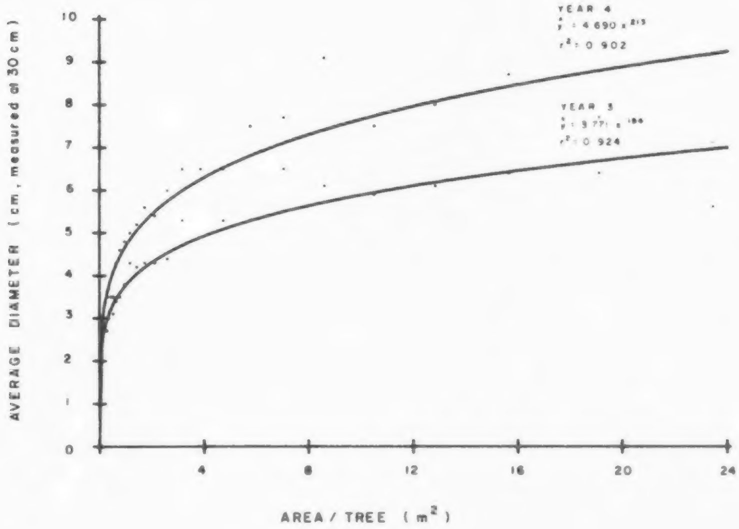


Figure 2-4

Growth/density by time for tree height, Domtar 8

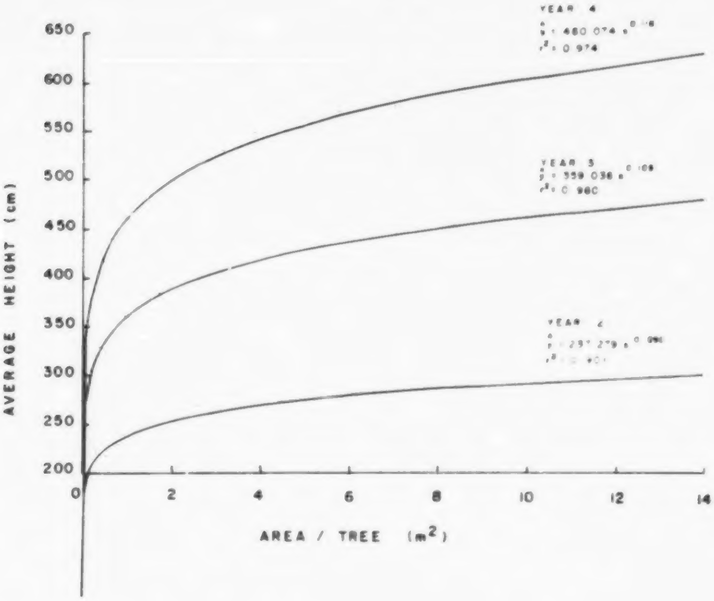


Figure 2-5

Growth/density by time for tree height, Grenville 32

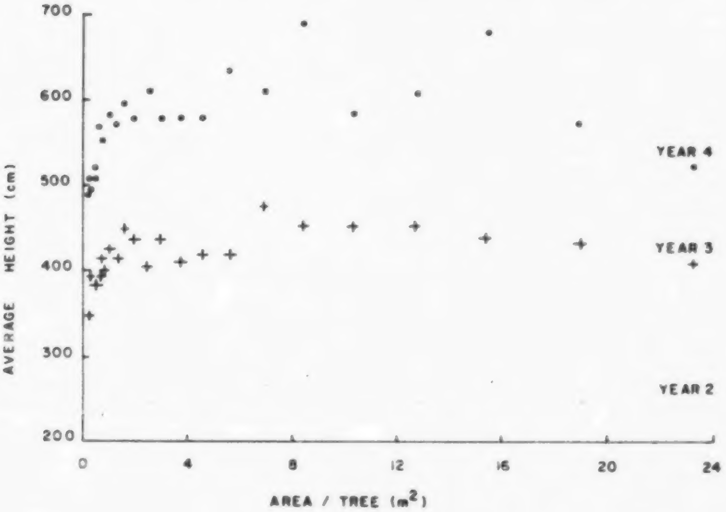


Figure 2-6

Growth/density by time for basal area (at breast height) x tree height at Domtar 8

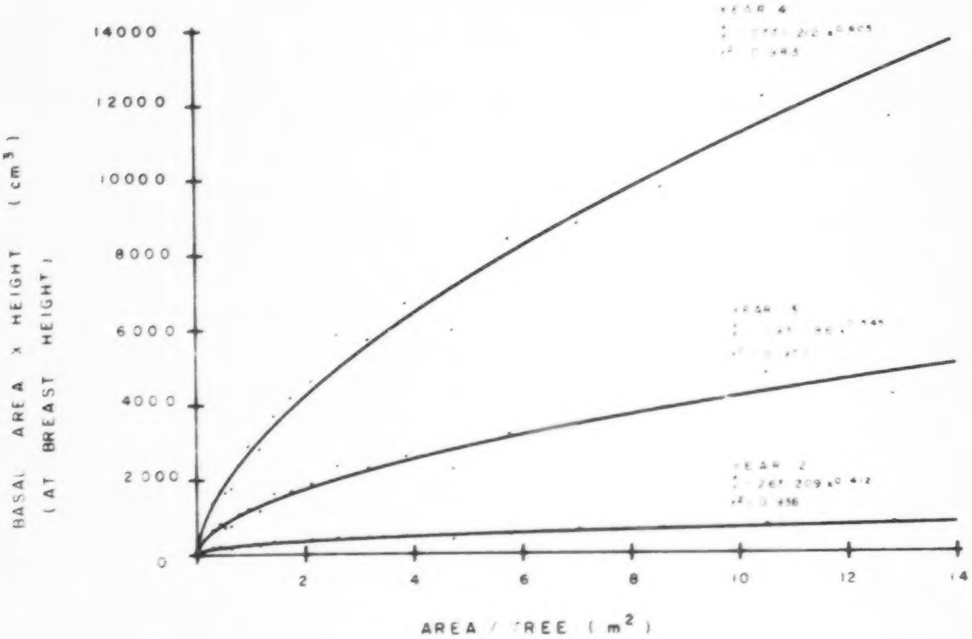
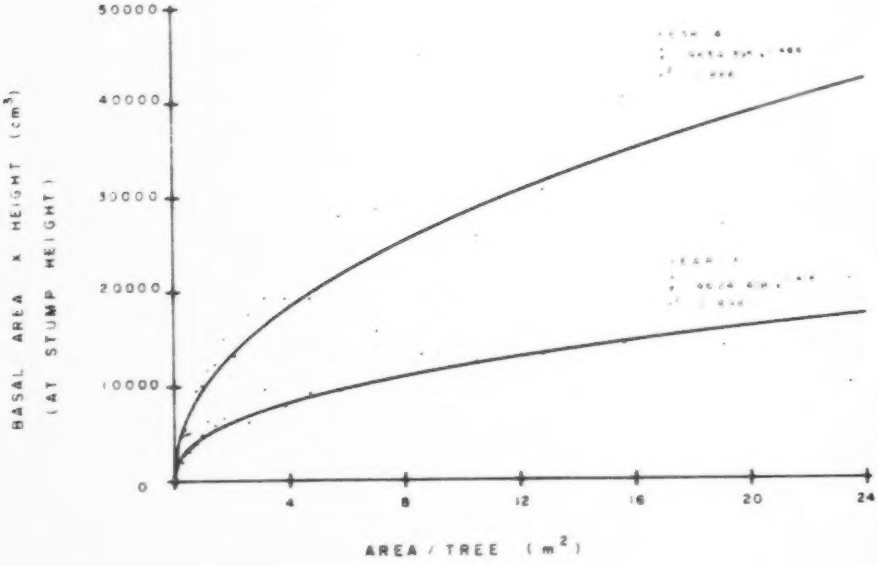


Figure 2-7

Growth/density by time for basal area (at Stump height) x tree height at Grenville 32



height (B.A. x Ht.) is an estimate of volume per tree at a given spacing in a given year. Without replication over site, this information cannot be used to project yield per unit area.

Growth in Relation to Time by Density

A more traditional approach to dealing with the growth data is to relate growth over time to density. With only four years of growth, regressions were not felt to be appropriate. Average growth data for a range of densities are given to show trends. Data from the Domtar 8 site only are presented in Figures 2-8, 2-9, 2-10 and 2-11.

At year two, diameter growth (Figure 2-8) at the widest spacing is twice the diameter growth at the smallest spacing. This range has increased to two and a half times by year four.

For basal area (Figure 2-9), the difference in growth between the smallest and widest spacings has increased exponentially from two and a half times at year two to six and a half times at year four. The major increase occurs between years three and four.

In contrast, height growth has a 30 per cent differential at the widest over the narrowest spacing at year two. This remains constant to year four. Height is not responding to changes over density over time but rather is reflecting the character of the site.

At year two, a factor of 10 separates the widest from narrowest spacings for B.A. x Ht. This has increased to a factor of 12 by year four. The spread increases dramatically at year three. The above information models the growth of "a tree" over time at various available growing areas.

Figure 2-8

Growth/density by time for diameter at breast height, Domtar 8

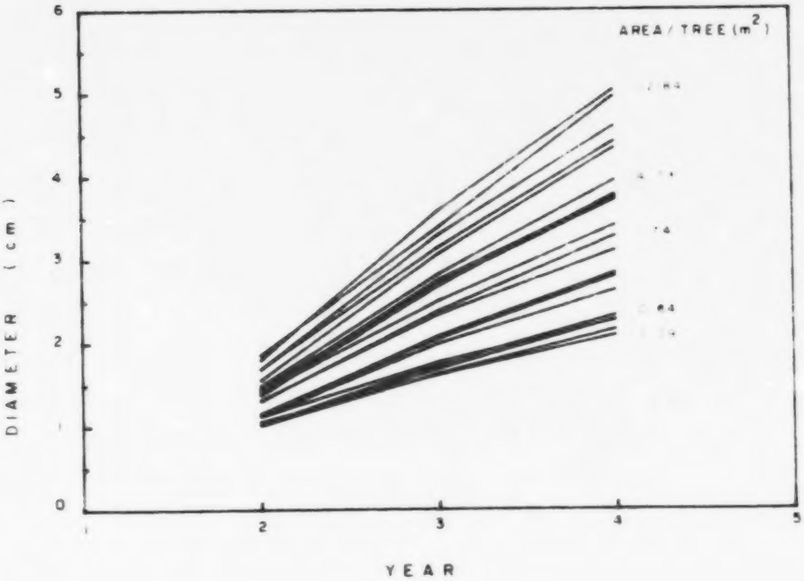


Figure 2-9

Growth/density by time for basal area at stump height, Domtar 8

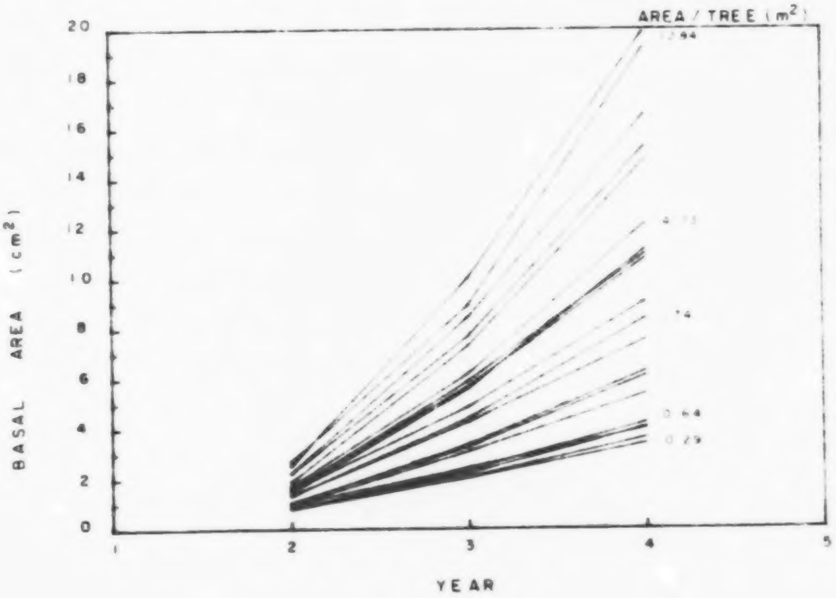


Figure 2-10

Growth/time by density for tree height, Domtar 8

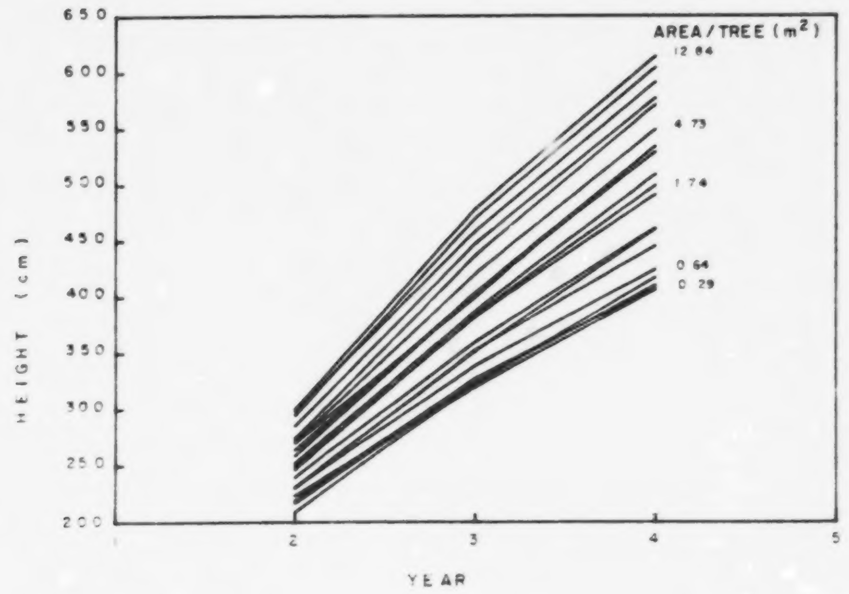
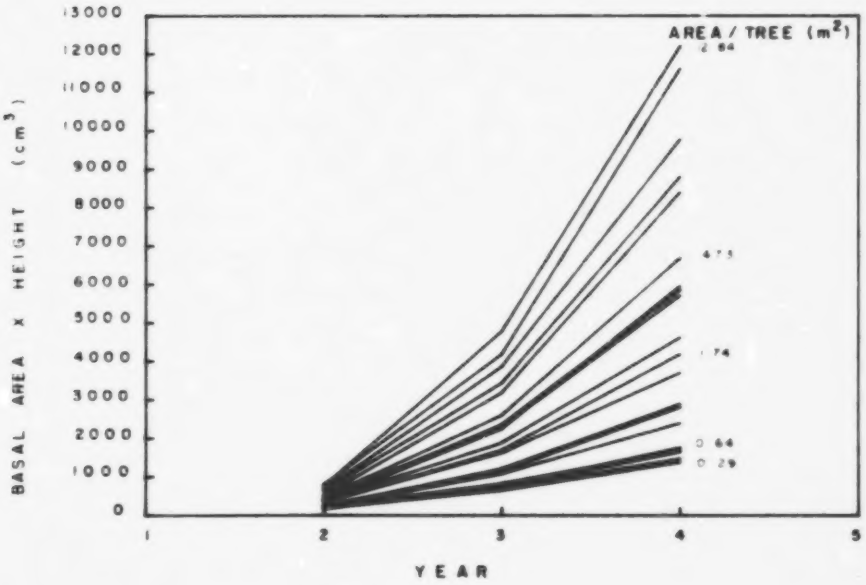


Figure 2-11

Growth/time by density for basal area
(at breast height) x tree height, Domtar 8



3/2 Power Law

As growth proceeds over time, density will induce mortality, the timing and extent of which must be determined. Has mortality been a factor during the four years of either the Grenville 32 nelder or the Domtar 8 nelder?

The concept of a maximum size-density relationship is a basic principle of biology. As expressed by Drew and Flewelling (1977), the relationship adopts the form:

$$v = a - 1.5 \text{ Ln } p$$

Where: v = mean individual tree volume
p = stand density
a = a constant
Ln = logarithmn

For a given density there is a maximum tree size which, if exceeded, will cause mortality.

Similar mean tree volume - stand density equations were developed for the Domtar 8 data for years two, three and four and are shown in Figure 2-12 and summarized in Table 2-5.

While the slopes are approaching a value of -1.5, there would appear to be a number of years to go before it is reached. Therefore, the maximum size-density relationship has not been reached and mortality due to density is not yet a factor. This explains the overwhelming influence of density on yield, i.e., ever-increasing densities producing ever-increasing yields.

Table 2-5

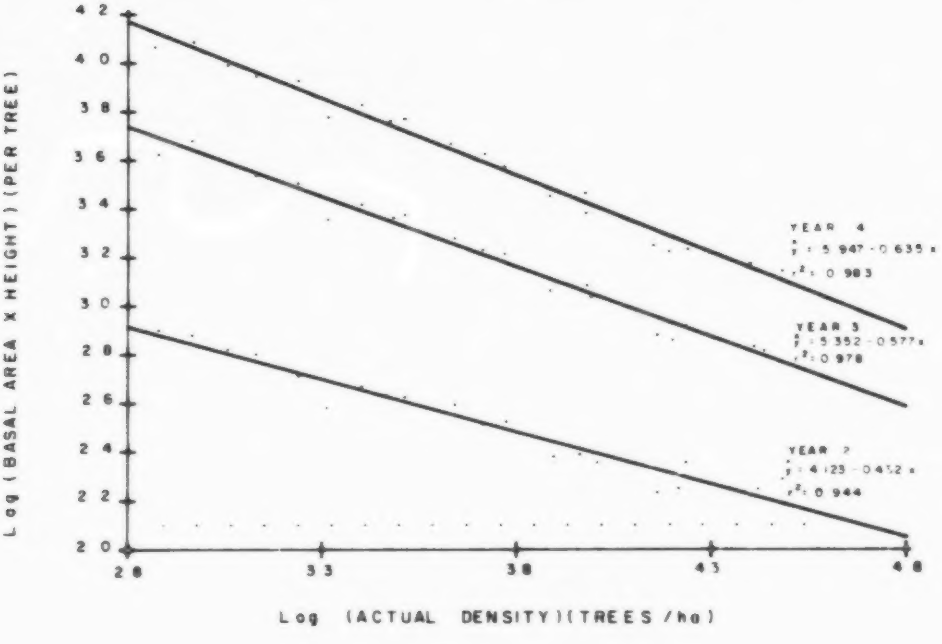
Tree volume - stand density equations for Domtar 8

Year 2	$Y = 4.123 - 0.432\ X$	$r^2 = .944$
Year 3	$Y = 5.352 - 0.577\ X$	$r^2 = .978$
Year 4	$Y = 5.947 - 0.635\ X$	$r^2 = .983$

$\ln v = a - 1.5 \ln p$

Figure 2-12

3/2 power law. Log individual tree volume vs stand density, Domtar 8



Comparison of Sites

Regressions of B.A. x Ht. (cm^3, based on DBH) versus area/tree (m^2) were prepared for both nelders in year four. Diameter at breast height information is available for G-32 only in year four.

For G-32: $Y = 4827.790\ x^{.416}$ $r^2 = .824$
For D-8: $Y = 2771.212\ x^{.605}$ $r^2 = .983$

These regressions were compared according to the analysis of variance procedure to compare regression lines outlined by Snedecor and Cochran (1937). At the one per cent level these regressions were significantly different. P. x euramericana clone 'DN 17' reacts differently to spacing on each of these two sites.

From Figure 2-13, it can be seen that greater growth is achieved initially at the G-32 site. The difference in growth lessens as area per tree increases. This information has important silvicultural implications.

Rotation Age: The Classical Approach

Rotation age is generally set at the intersection of the Mean Annual Increment (MAI) and Current Annual Increment (CAI) curves. Normally stand volume measures are used.

Diameter growth is most sensitive to density. Given the incomplete data set over time and using diameter increment, optimal rotation ages for specified densities were projected (Figure 2-14) and are summarized in Table 2-6. These projections are based on diameter response at breast height for the Domtar 8 Nelder.

Figure 2-13

Comparison of regression lines

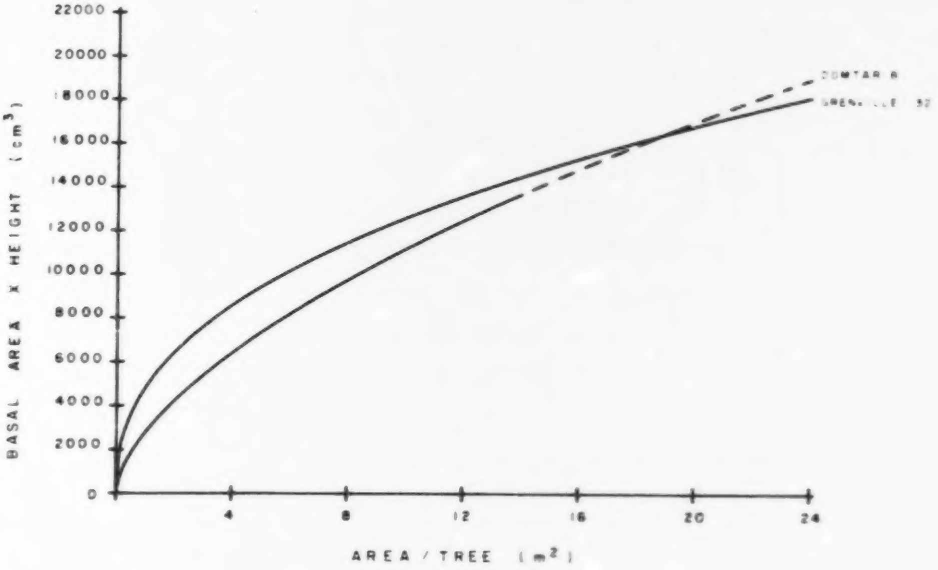


Figure 2-14

Mean annual increment and current annual increment (based on diameter at breast height), Domtar 8

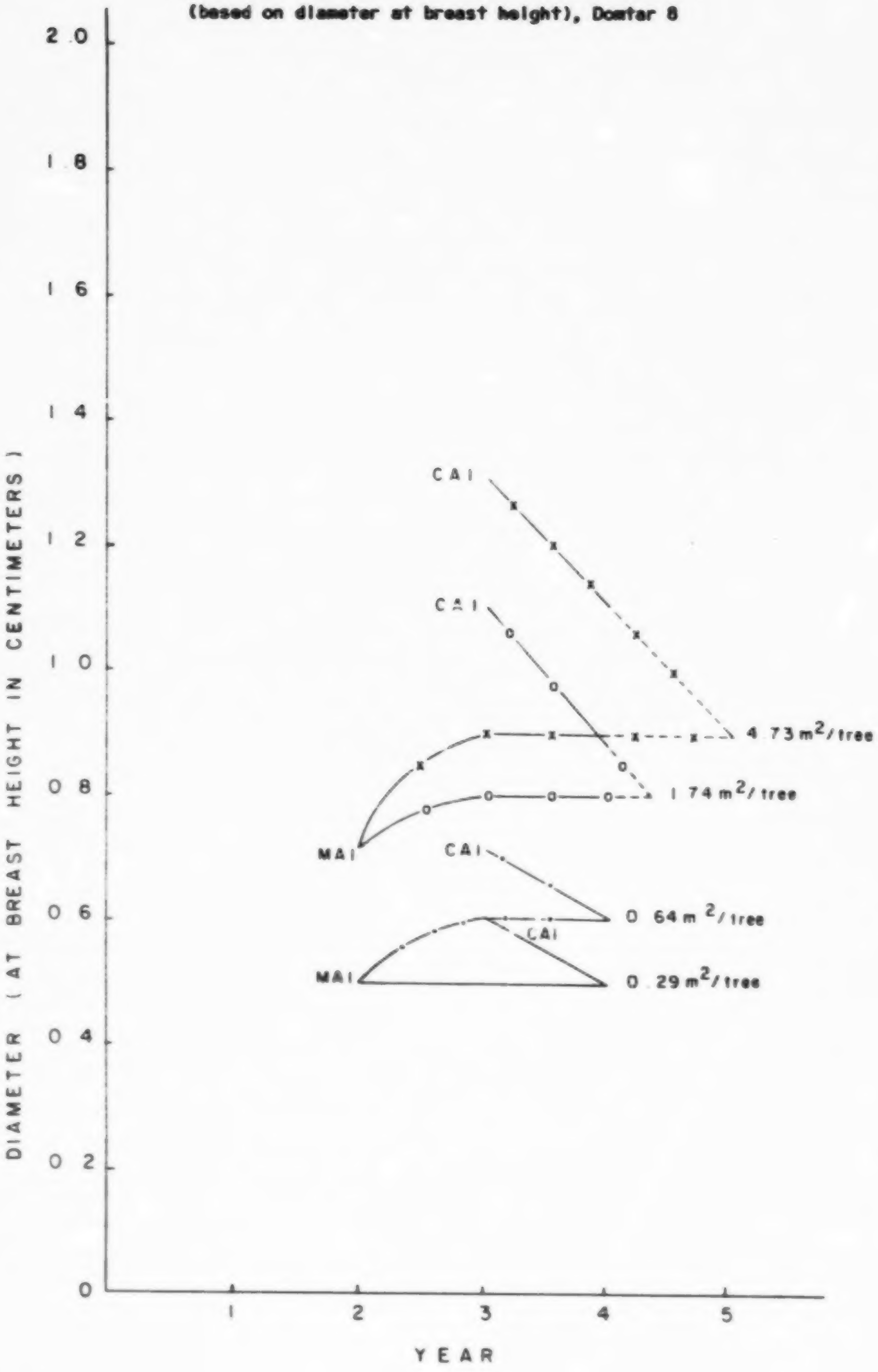


Table 2-6

Mean annual increment and current annual increment (diameter at breast height) for Domtar 8

		Rotation ages	
m^2/Tree	Trees/ha	As Projected (Figure 2-14)	(Raitanen, 1978)
.29	34,564	4.0 year	2.0 year
.64	15,616	4.0 year	3.0 year
1.74	5,755	4.5 year	4.5 year
4.73	2,112	5.0 year	7.0 year

The projected rotation ages are compared with those discussed and reported earlier (Raitanen, 1978). With time and density taken into account, the biological production function for cultivar 'DN 17' on the Domtar 8 loam site is not as was originally assumed. The comparison suggests that our highest density plantations should be left two years longer on the stump.

The extrapolation at 4.73 m^2/tree may be highly inaccurate; a clustering effect does occur at four to five years of age.

Variation and Site

In this approach, each arc is considered a treatment and each Nelder a replication of a trial.

The span over which this information can be applied is directly proportional to the range of sites covered within the trial. For a single trial, only one clone should be used.

For comparison purposes, the "tree growth" data was converted to mean annual increment in terms of oven-dry kilograms per tree per year. An analysis of variance and multiple comparison of means was then completed. This information is provided in Table 2-7 for years three and four.

From year three to four the number of ranks decreases from seven to five. Table 2-7 does illustrate the overwhelming preponderance of the density effect.

Discussion

Growth has been determined over a range of densities at years two, three and four, on two contrasting sites. Diameter, basal area and tree volume are all highly correlated to the available growing area per tree. Height can be more strongly controlled by site and initial site conditions. At this stage of growth all curves are exponential as expected.

The response of clone 'DN 17' to density was different on the two sites. This suggests a site x density interaction. At high densities, 'DN 17' was better able to exploit the moderately well drained sandy loam as opposed to the imperfectly drained loam. The former soil type would be preferable for a management system based on a high initial plant density if 'DN 17' was the chosen clone. But is 'DN 17' the "best" clone for a high density management system? Further studies are required to answer this question.

The Nelder design provides a very efficient means of determining the final crop size for a range of initial planting densities. It is a systematic, individual tree design, but does not provide for an estimate of the variation caused by site nor does it allow for estimates of yield per unit area. A partial solution involves considering each arc as a plot and each Nelder as a replication of a trial consisting of a

Table 2-7

**Average oven-dry kilograms/tree/year
for D-8 and G-32
(Duncan's multiple comparison of means
at 1% significance)**

Year 3									Year 4						
Arc	u	Rank							Arc	u	Rank				
		1	2	3	4	5	6	7			1	2	3	4	5
19	1.47	|							18	3.03	|				
17	1.42	|							20	2.69	|				
20	1.41	|							19	2.56	|				
18	1.36	|							17	2.26	|	|			
16	1.04	|	|						16	2.18	|	|			
13	.90		|	|					14	1.61		|	|		
15	.87		|	|	|				15	1.52		|	|		
14	.86		|	|	|				13	1.49		|	|		
12	.73		|	|	|	|			12	1.44		|	|	|	
11	.65		|	|	|	|	|		10	1.13			|	|	|
10	.64		|	|	|	|	|		11	1.11			|	|	|
9	.59			|	|	|	|	|	9	.96			|	|	|
8	.53			|	|	|	|	|	8	.82			|	|	|
7	.46				|	|	|	|	7	.77			|	|	|
6	.40					|	|	|	6	.69			|	|	|
5	.32					|	|	|	5	.53				|	|
3	.31						|	|	3	.42					|
4	.29						|	|	4	.41					|
2	.27						|	|	2	.41					|
1	.22							|	1	.37					|

u= mean of actual for D-8 and G-32

series of Nelders. If more than one clone is involved in the series then a hierarchial design is required. This range wide testing would be applicable to the span of clones and sites involved. Good quality yield information can come only from block production plantings wherein plots are located in a random as opposed to a systematic fashion.

Generally, it has been shown that greater tree density results in greater yield. This relationship will remain true until the maximum tree size-density relationship, known as the 3/2 Power Law, is exceeded and density begins to affect survival. Once the maximum tree size which can be supported at a given density has been exceeded, mortality may occur and yield will no longer increase. At four years, the maximum tree size had not yet been reached at even our highest plant densities. Thus mortality as a result of crowding has not yet been a factor in either of the Nelders.

For the Domtar 8 site (imperfectly drained loam) the intersection of the CAI and MAI curves for diameter occurred at age four for our highest density of 0.29 m^2/tree. Theoretically, this would be the rotation age. From Figure 2-8, the diameter would be 2.0 cm and from Figure 2-10 the height would be 400 cm. Rather than stating that harvest will occur at age four, it may be more useful to state that harvest will occur when the material is 2.0 cm in diameter and 400 cm in height. The latter defines a state dependent relationship: a crop is not harvested at a certain age but rather at a certain size. State dependence has an important commercial implication. A whole series of factors such as weather, fertilization and weed control can intervene and make time dependency irrelevant. The required marketable size of the crop remains critical. Plant size can be manipulated by a combination of density and time. Knowledge of how this manipulation can occur is essential in understanding the management systems available in bringing a crop to marketable size.

Conclusion

Nomenclature of Management Systems

An infinite number of management systems can be defined by the selection of various combinations of density and rotation age. A problem of common descriptive nomenclature exists. The convention we have adopted is to name the management system after the density employed. For each density an "optimal" rotation must be selected. A mental image of the stand can thus be created by the nomenclature.

In previous work (Raitanen, 1978), management systems were named. The new nomenclature is compared with the old:

New		Old
System 35K	vs.	mini-rotation density 35,864 per ha.
System 4K	vs.	midi-rotation density 4,303 per ha.
System 1K	vs.	short-rotation density 1,077 per ha.

When an "optimal" rotation age has been determined, it may be added to the system of management, e.g., System 35K implies a stand of approximately 35,000 plants per ha to be managed on a four year rotation.

Characterization of Management Systems

Table 2-8 provides characteristic tree size and tree increment for the given density, rotation, clone and site combinations.

One approach to setting rotation is to determine what the "economic tree size" should be and then to select a density that will provide this quality of resource at the least cost.

Thus, for the Grenville 32 site and clone 'DN 17' combination, a tree size with a minimum of 3.0 cm in diameter at stump height and a minimum height requirement of 500 cm could be produced with the following systems of management:

System 35K at 4 year (35K 4)
System 23K at 4 year (23K 4)
System 16K at 4 year (16K 4)
System 10K at 4 year (10K 4)
System 7K at 4 year (7K 4)
System 5K at 4 year (5K 4)

A separate analysis is required to determine the system of least cost per oven-dry tonne. An economic evaluation model is provided in Chapter 9.

It is most important that harvest "expectations" regarding tree size are met. The entire tree handling system from the stump to the mill is geared to tree size.

Table 2-8

Characterization of management systems

Management System	Rotation Year	Predicted Diameter (cm) @DBH	Predicted Diameter (cm) @30 cm	Predicted Height (cm)		Predicted MAI (kg/tree/yr)		Total kg/tree @ rotation i.e. MAI x Rotation Age	
		D-8	G-32	D-8	G-32	D-8	G-32	D-8	G-32
System 35K (34,564/ha)	2	1.0	---	212	226	.03	---	.05	---
	3	1.6	3.0	314	357	.07	.29	.19	.88
	4	2.1	3.6	398	501	.11	.43	.42	1.73
System 23K (23,241/Ha)	2	1.0	---	220	237	.03	---	.06	---
	3	1.7	3.9	328	408	.08	.35	.24	1.04
	4	2.3	3.9	417	505	.13	.52	.53	2.08
System 16K (15,616/Ha)	2	1.1	---	228	224	.03	---	.07	---
	3	1.9	3.5	342	398	.10	.41	.03	1.23
	4	2.5	4.3	437	530	.17	.63	.68	2.51
System 10K (10,446/Ha)	2	1.2	---	236	245	.04	---	.08	---
	3	2.0	3.7	357	425	.12	.49	.37	1.46
	4	2.7	4.7	458	560	.22	.76	.87	3.03
System 7K (7,013/Ha)	2	1.3	---	245	256	.05	---	.10	---
	3	2.2	4.0	373	424	.16	.57	.47	1.72
	4	3.0	5.1	480	580	.28	.91	1.10	3.64
System 5K (4,714/Ha)	2	1.3	---	254	241	.06	---	.11	---
	3	2.4	4.4	390	414	.19	.68	.58	2.03
	4	3.3	5.5	503	585	.35	1.09	1.40	4.38

Technology of Management Systems

Each management system will have a characteristic technology and cost profile. These are briefly outlined below.

System 35K:

The high density of this system requires large planting costs ($2,000.00/ha for OMNR Brockville District in 1981 for hand planting). These costs could readily be reduced to one-third of their value by the use of conventional mechanical planters, providing a prime mover with suitable floatation is available (planting takes place when the soils are saturated). Harvesting costs would also be in the order of $33 US per tonne (Mattson, 1981). A special harvesting system would have to be developed for this density of planting.

System 4K:

Planting costs for system 4K for the Brockville operating unit were $300.00/ha for 1981. Machine planting at this density would still be an asset. Harvesting costs would be in the order of $17.60 US per tonne (Mattson, 1981). A conventional feller-buncher-chip harvester system could be used.

System 1K:

This is the conventional fibre production system. Planting costs are very reasonable at $100.00/ha (Cornwall operating unit 1981 production costs). Havesting costs are well established in the order of $11 US per tonne.

3 SOILS: THE FOREST FOUNDATION

Soils form the forest base and the integrity of future stands is dependent upon how well this base is identified and managed. Failure to take the variability of soils into account has traditionally resulted in major errors in silvicultural judgement in the choice of species and treatments when plantations have been established.

An intensive soil survey is essential, therefore, for the successful establishment and management of a fast-growing hardwood plantation, since it provides for stratification of the land base on which plantations are to be established.

The Land Base

The soils of eastern Ontario are extremely heterogeneous. Three separate periods of glaciation have had a major impact upon the surficial geology of the area. Following the last period of glaciation, the Champlain Sea temporarily submerged portions of the region. The present soils have developed on a variety of materials ranging from fine marine clay to unsorted glacial tills and coarse outwash sands. It is not uncommon to find several different geologic materials present within a single soil profile. Limestone bedrock predominates throughout most of the area, although the acidic Precambrian Shield is present in the central and northern areas. The topography is generally flat to gently rolling. Since the South Nation River, a major drainage system, falls only an average of 45 centimetres per kilometre, drainage tends to be slow and restricted in many areas. The physiography of the area is reviewed in greater detail by Chapman and Putnam (1966); major features are shown in Figure 3-1.

Settlement and Land Use

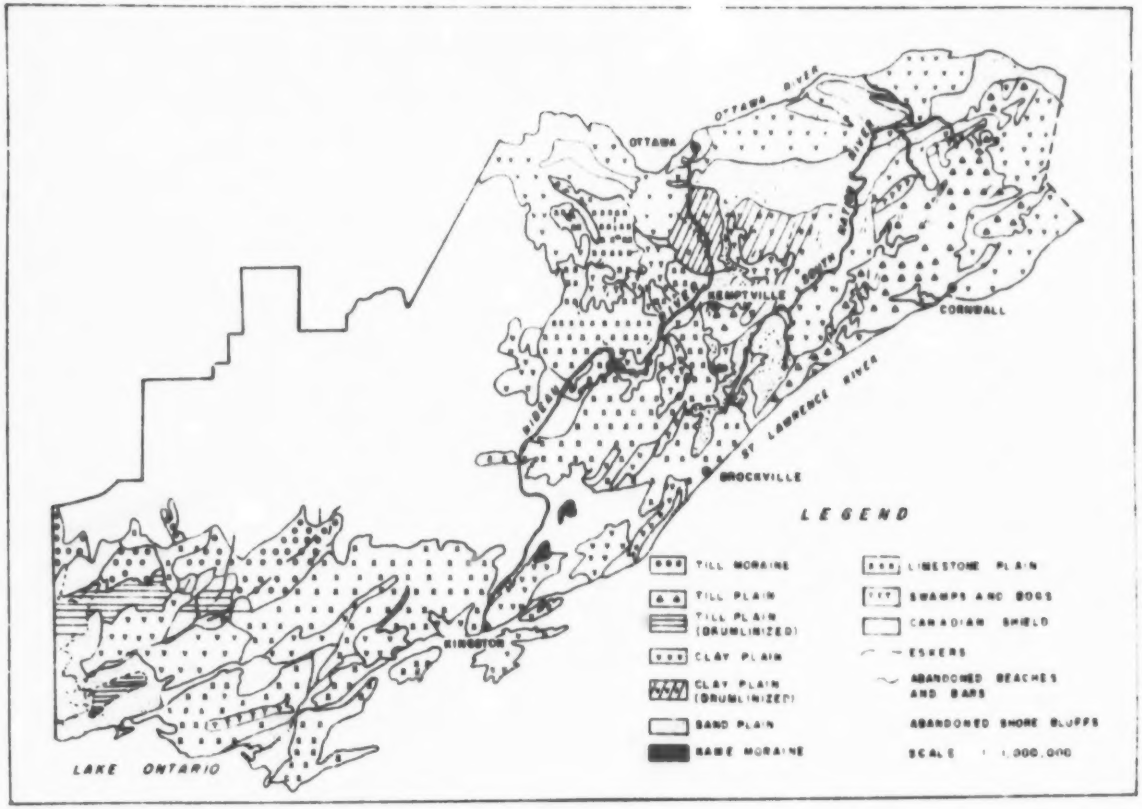
Eastern Ontario was one of the first areas to be settled in the province. A detailed land survey was carried out in the late eighteenth century and land was granted in lots varying from 40 to 80 hectares to incoming United Empire Loyalists and other pioneer immigrants.

By the mid-nineteenth century an elaborate network of roads was well established and much of the natural forest was cleared to make way for agriculture. The forest cover in several counties was reduced to less than eight per cent of the total land area.

Dramatic changes in agricultural technology over the past few decades have had a major impact on land use. As farming operations became more intensive, many parcels of land were considered to be of marginal value

Figure 3-1

Major physiographic features of eastern Ontario
After Chapman and Putnam, 1966


OTTAWA
OTTAWA RIVER
RIDEAU
KEMPTVILLE
SOUTH NATION RIVER
CORNWALL
ST LAWRENCE RIVER
BROCKVILLE
KINGSTON
LAKE ONTARIO
LEGEND
TILL MORAINE
TILL PLAIN
TILL PLAIN (DRUMLINIZED)
CLAY PLAIN
CLAY PLAIN (DRUMLINIZED)
SAND PLAIN
BARE MORAINE
LIMESTONE PLAIN
SWAMPS AND BOGS
CANADIAN SHIELD
ESKERS
ABANDONED BEACHES AND BARS
ABANDONED SHORE BLUFFS
SCALE 1 : 1,000,000

for agriculture. Variable soil types, soil drainage problems and excessive stoniness adversely affected farm operations and crop yields. Many areas unprofitable for farming are currently idle, producing no worthwhile crop. It is on these areas that fast- growing hardwoods plantations are being established.

Early Observations on Plantation Growth and Soils

In the early stages of the hybrid poplar program, the results observed in young plantations were extremely variable. Early practice consisted of planting a single clone over large areas regardless of differences in site. On many of these areas major differences in tree growth often were later associated with variation in soil types.

A number of plantations were established between 1972 and 1975 before the sensitivity of clones to different sites was fully recognized. These have enabled the documentation of differences in growth of a single clone, 'I-45/51', on several different soils (Table 3-1). Although the ages vary, the same establishment and tending procedures were used in all examples. The sites were ploughed and disced the year prior to planting. Planting was done in early spring of the next year using 25-cm long unrooted cuttings. Mechanical cultivation maintained weed control during the first three years. The following are brief descriptions of the soils on which the plantations in Table 3-1 were established (detailed descriptions are in Table 3-2).

Table 3-1

Plantations of clone 'I-45/51' established on contrasting sites. Heights and diameters as of December, 1980

Plantation	Location	Year Established	Initial Density Trees per Hectare	9% Per cent Survival in 1980	Average Height (m)	Average Annual Height Growth (m)	Average Diameter Breast Height (cm)
Johnson North	North Augusta	1972	1100	90	10.2	1.13	11.8
SNA 56*	Berwick	1974	1100	-----------Survival Limited-----------			
Codrington	Codrington	1974	760	80	12.0	1.71	16.1
Domtar 1	Avonmore	1975	1100	80	7.5	1.25	7.1

* SNA 56 plantation is included for comparison, although by age four, very few trees have survived.

Johnson North Soil

An imperfectly drained loam over gravelly silt loam ranges from neutral to strongly alkaline with increasing depth. Root development occurs well below the 50 cm depth. This fine textured soil is well structured and slightly compact in the lower profile.

SNA 56 Soil

This is a poorly drained sandy loam over fine loamy sand soil that is acidic and without structure. The profile development is shallow. The light colour of the Ap horizon indicates an organic matter content of less than one per cent. Root development is limited to the upper 20 cm of the profile.

Table 3-2

Table 2: Detailed soils description

Description	Johnson North			SNA 56		
Horizon	Ap	Bt	Ck	Ap	Bfg	C
Depth (cm)	0 - 18	18 - 49	49 - 100	0 - 13	13 - 21	21+
Wet Colour	10 YR 3/2	10 YR 3/4	2.5 YR 4/2	10 YR 3/2	10 YR 5/4	2.5YR 5/6
	Very Dark Grayish Brown	Dark Yellowish Brown	Dark Grayish Brown	Very Dark Grayish Brown	Yellow-Brown	Light Olive Brown
Texture	Loam	Silt Loam	Silt Loam	Sandy Loam	Fine Sandy Loam	Fine Loamy Sand
Mottles	None	Very Few, Fine, Faint	Few, medium distinct	Few, indistinct	Common, and prominent	Coarse,
Structure	Weak, Crumbly Fine	Moderate, Blocky, Fine	Sub-Angular Blocky, Fine	-----------Amorphous-----------		
Consistence:						
Wet	------Slightly Sticky, and Non-Plastic-			Slightly Sticky & Plastic	--Non-sticky & --------- Non-Plastic	
Moist	------- Very Friable ----		Friable	-Very Friable when moist-------------		
Dry				-Soft when dry----------------------		
Roots Abundance	Plentiful	Few	Very Few	Plentiful	Few	None
Roots Size	Fine	Medium	Fine	Medium	Very Fine	
Clay Films		Few Thin	Few Thin			
Concretions						
Free Carbonates			Moderate			
Coarse Fragments		Many Cobbles	Many Cobbles and boulders			
Horizon Boundaries	Abrupt Wavy		Abrupt Wavy	Abrupt Smooth		Gradual Smooth
pH	6.0	7.15	8.05	5.6	5.8	5.7
Drainage	Imperfectly Drained			Poorly Drained		

Description	Codrington				Domtar 1		
Horizon	Ap	Bt	B-C	C	Ap	B	Ck
Depth (cm)	0-22	22-58	58-70	71+	0 - 16	16 - 35	35+
Wet Colour	10YR 3/3 Dark Brown	10YR 5/3 Brown	7.5YR 4/2 Dark Brown	7.5YR 4/4 Dark Brown	10 YR 2/2 Very Dark Brown	5Y 7/2 Light Gray	2.5Y Olive Yellow
Texture	Silt loam	Silt Loam	Silt Loam	Silt Loam	Loam	Silty Clay	Silty Clay
Mottles		Few, Fine Faint	Common,	Medium Faint		Many, Coarse and Distinct	
Structure	Moderate Crumb, Medium	Strong, Sub-ang. Blocky Medium	Strong, Sub-ang. Blocky Coarse	Strong, Sub-ang. Blocky Coarse	Weak, Crumb Fine	Strong, Platey Coarse	Weak, Sub- Angular Blocky Coarse
Consistence	--------- Very Friable------- ---------	Slightly Slightly	Sticky & Friable Hard--------------	Plastic	------Slightly sticky------------------ and plastic Very friable, soft-----		 Friable Slightly Hard
Roots Abundance	Abundant	Plentiful	Plentiful	Few	Few	Very Few	None
Size	Medium	Fine	Fine	Fine	Fine	Very Fine	
Clay Films		Discontinuous-------------- Thin	 -Moderately Thick---			Few Thin	Few Thin
Concretions							
Free Carbonate						Very Weak	Stron
Coarse Fragment					Few Cobbles	Few Cobbles	Cobbles Abundant
Horizon Boundaries	Abrupt Smooth	Diffuse Smooth	Diffuse ----- Smooth		Abrupt Wavy		Diffuse Smooth
pH	6.5	6.6	6.4	6.3	6.3	6.9	7.3
Drainage	Imperfectly Drained				Imperfectly Drained		

Codrington Soil

An imperfectly drained silt loam of neutral pH, the soil structure is well developed throughout the profile of this type of soil. The soil profile has developed to a depth of 70 cm but roots are present and well distributed at depths below 70 cm. There are no coarse fragments present in the profile.

Domtar 1 Soil

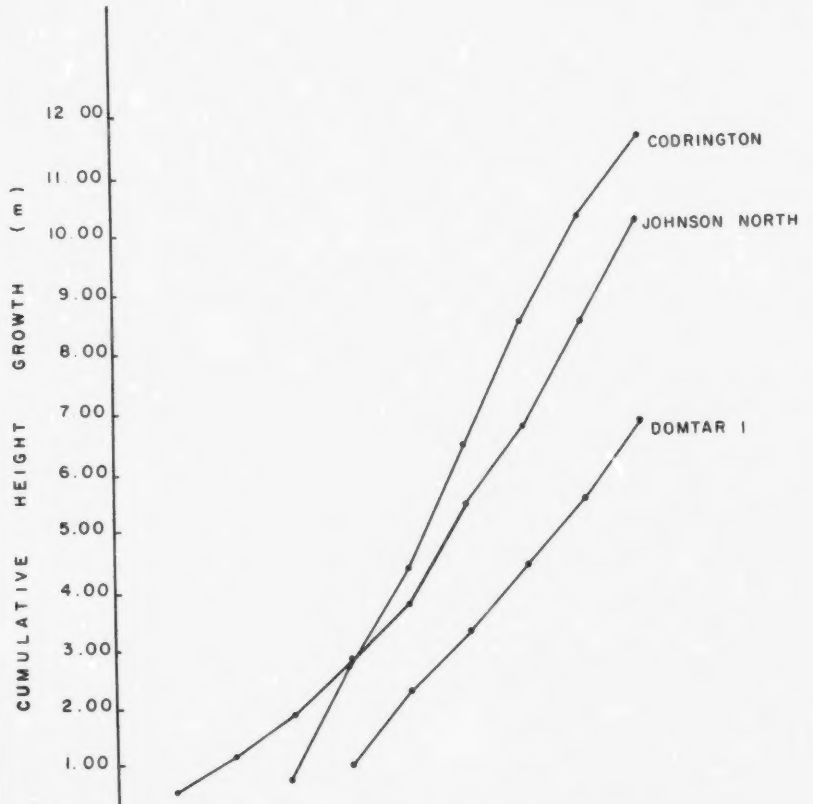
This is an imperfectly drained loam over silty clay with a neutral pH. The soil horizons are well structured and compact. Root development is limited to the upper 35 cm of the profile. The number and size of coarse fragments increases with depth.

Growth has varied considerably from site to site. On SNA 56 many of the trees were dead by age four. Trees growing on this site suffered severe damage from *Cytospera chrysoperma* (Pers) Fr. and *Dothichiza populea* Sacc. et Br. These two diseases are associated with many hybrid poplar clones growing under stress (Hubbes, 1979; Zsuffa, 1975). The surviving growth on this site consists primarily of coppice sprouts growing from the base of trees with dead tops. The Codrington plantation has always grown vigorously and remained free of insects and diseases. The Johnson North and Domtar 1 plantations have had minor leaf disease problems, e.g., *Marssonina brunea* (E. and E.) Sacc.

Distinct patterns of height growth are associated with the different sites. Cumulative height growth is shown in Figure 3-2. Although the Codrington plantation is two years younger, its trees are taller than those of

Figure 3-2

Cumulative height growth 'I-45/51' growing on three different sites



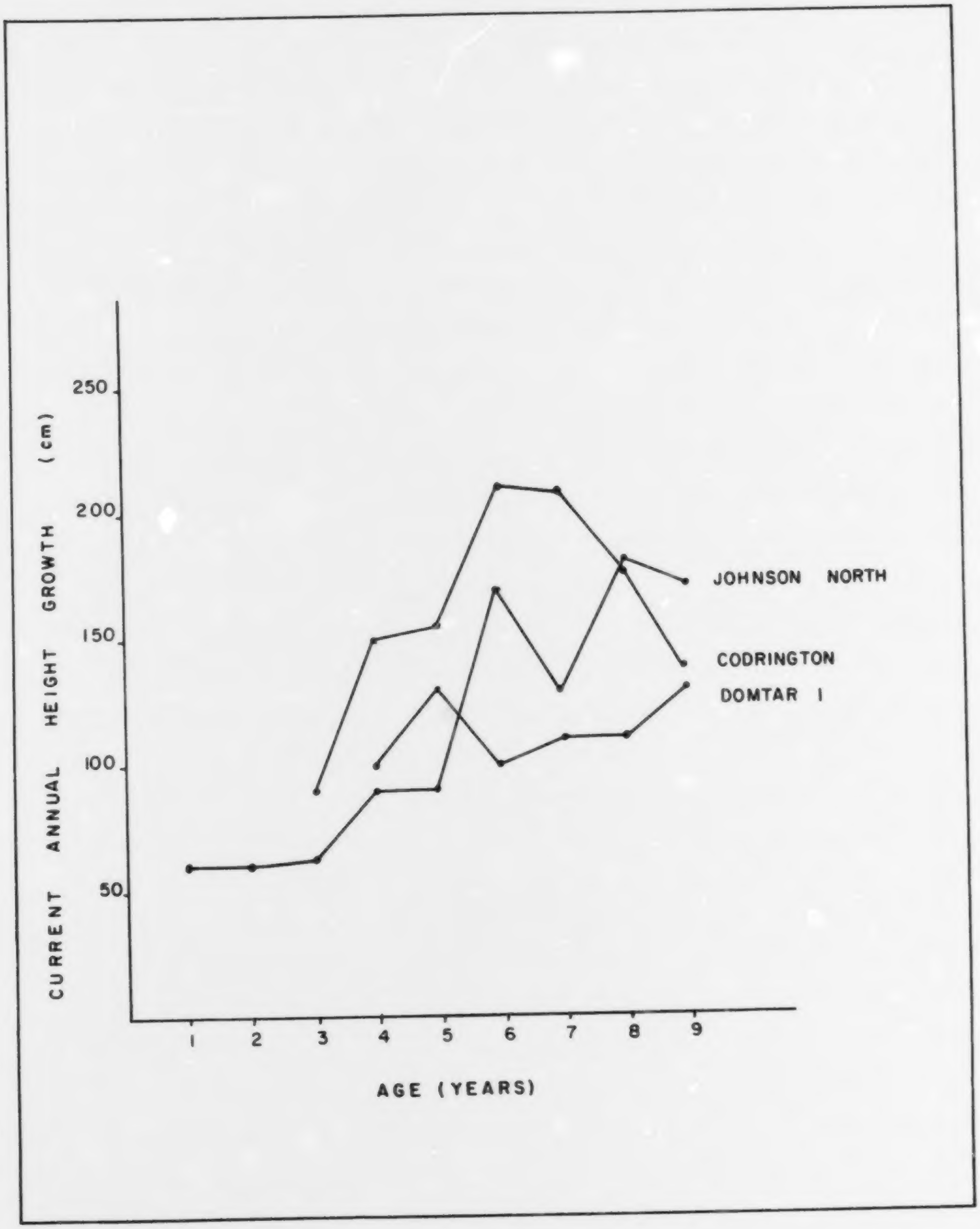
Data are based on three randomly selected trees on each site.

the Johnson North plantation. The height of the trees at Codrington has been greater than either those at Johnson North or Domtar 1 every year since year two. A comparison of the patterns of annual height growth (Figure 3-3) of the surviving plantations shows growth differences between sites. All plantations grew approximately the same height in year one. In succeeding years, differences in growth began to be apparent. The growth rate at Codrington accelerated rapidly and consistently until 1978. The Johnson North growth rate began to accelerate slightly, with considerable fluctuations, starting in 1976. The Domtar 1 growth rate has remained relatively slow and consistent since establishment. Considering the similarities between the soil of Domtar 1 and Johnson North (i.e., compacted lower soil profile), the growth may just be starting to accelerate at Domtar 1.

Although based on a very limited sample there are several different conclusions that can be drawn from this information. In an eight- to 10-year rotation, Codrington would be the most productive site; yet in the past two years its rate of growth has significantly lessened. This may be a result of the trees having fully exploited the rooting volume of the soil. In contrast, Domtar 1 appears to have a slower rate of rate of growth, but less variation, and represents a situation in which a longer rotation would be necessary to achieve the same results as at Codrington. A more complete analysis of the soils in relation to growth will be given later in this paper.

Figure 3-3

Current annual height growth for '1-45/51' growing on three different sites



Data are based on three randomly selected trees on each site.

Soil Surveys

Development and Selection of Scale

It is apparent that if soil features that affect growth can be identified and mapped, then more effective planning in plantation establishment will result. Soil surveys determine the extent and distribution of various soil types. The scale of the soil survey depends on the intensity of management. Scales as large as 1:2 000 may be appropriate for intensive forest management (Armson, 1977). In eastern Ontario, a mapping scale of 1:2 000 was selected. This scale is sufficiently large to identify the soil variation present and to provide adequate base information for intensive forest management. Soil types as small as 0.2 hectares can be identified and mapped. A preliminary step involves stratifying the area to be surveyed into suitable and unsuitable sites for hybrid poplar plantations. Intensive soil surveys are then carried out on the suitable sites for hybrid poplar. Unsuitable sites for fast-growing hardwoods are areas where soil characteristics are at extremes. Areas where the bedrock is less than 60 cm below the surface, or the soil consists of excessively well-drained sands, are unable to supply sufficient moisture for hybrid poplars. Other areas, with excessive moisture, such as very poorly drained, fine, massive clay soils, are poorly aerated and limit growth.

Aerial photographs, changes in vegetation and changes in surface relief aid the soil surveyor in delineating the position of the different soil types. Traverse lines at approximately 40 m intervals are made and the soil profiles are systematically examined either by using a spade to expose a profile or by use of a soil auger.

The delineation of different soil types is based upon soil texture, depth, drainage, colour and stoniness. The various soil types are described objectively by examination of the macroscopic features of the soil profile. A detailed profile description (Table 3-3) and the related profile diagram (Figure 3-4) are prepared. A comprehensive and objective soil description provides the opportunity for special interpretations to be made at a later date (Armson, 1977) once the relationship between clones and sites is better understood, thus increasing the usefulness of the soil survey.

Agricultural soil surveys, which have been carried out for most of southern Ontario, are of limited value for the hybrid poplar program. The commonly used scale 1:63,360 is more suitable for planning on a regional basis. Figure 3-5 shows a portion of the agricultural soil survey for Grenville County (Richards and Matthews, 1944) and can be compared with the intensive soil survey map for Johnson North (Figure 3-6). Associated with the major difference in scale of mapping, there is a considerable discrepancy between the mapping units on the two surveys. Also, agricultural soil surveys are generally based on the soil variations that occur in the cultivated plow layer (0-18 cm) rather than the entire profile. As Armson (1977) points out, "Undoubtedly, textural differences within the solum are important, but whether [or not] the arbitrary setting of a surface 15-18cm in depth for their delineation is justifiable for a soil survey of land whose uses may be largely non-agricultural, is debatable." A forest crop is established for a rotation of several years, during

Table 3-3

Example of soil profile description for Johnson North

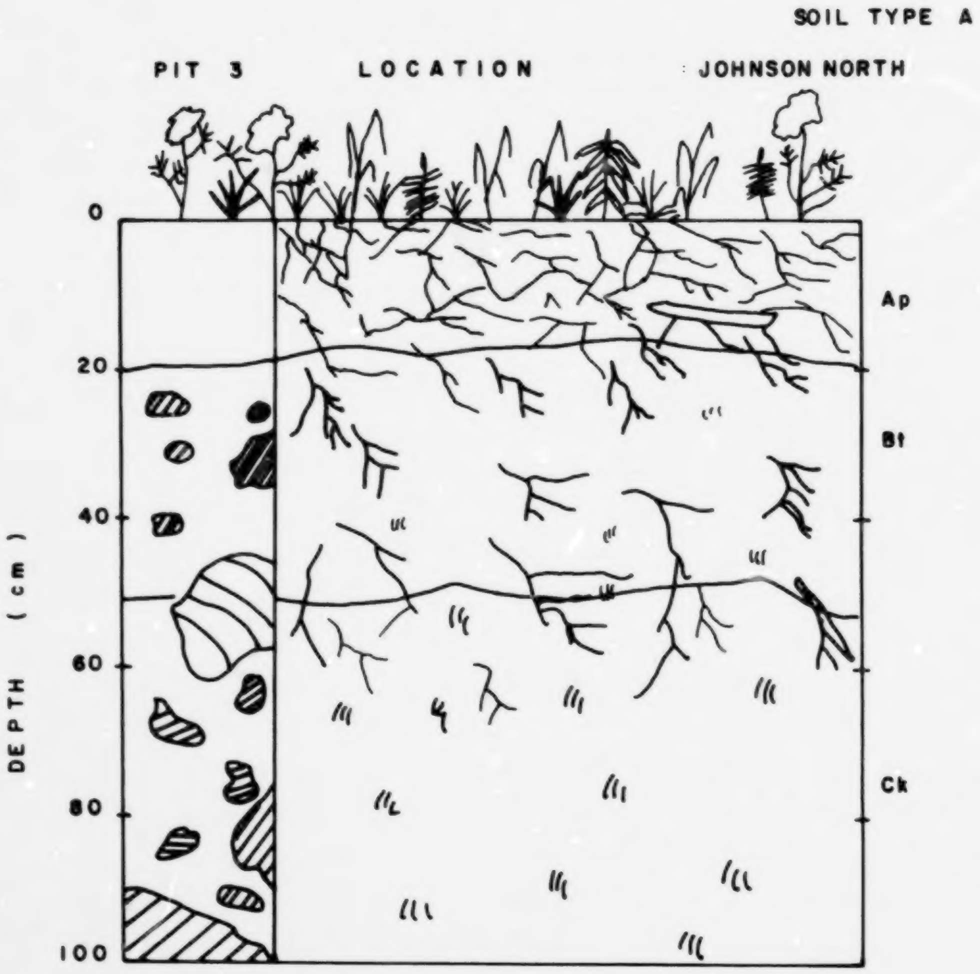
SOIL TYPE A

PIT 3 LOCATION : JOHNSON NORTH — NORTH AUGUSTA

HORIZON	Ap	Bt	Ck		
DEPTH (cm)	0-18	19 - 49	50-100		
COLOUR MOIST	10YR 3/2 VERY DARK GRAYISH BROWN	10 YR 3/4 DARK YELLOW BROWN	2.5 YR 4/2 DARK GRAYISH BROWN		
TEXTURE	LOAM	SILTLOAM	SILTLOAM		
MOTTLES - ABUNDANCE		VERY FEW	FEW		
SIZE		FINE	MEDIUM		
CONTRAST		FAINT	DISTINCT		
STRUCTURE — GRADE	WEAK	MODERATE	MODERATE		
KIND	CRUMB	SUB-ANGULAR BLOCKY	SUB - ANGULAR BLOCKY		
CLASS		FINE	FINE		
CONSISTENCE - STICKINESS	SLIGHTLY STICKY	SLIGHTLY STICKY	SLIGHTLY STICKY		
WET PLASTICITY	NON PLASTIC	NON PLASTIC	NON PLASTIC		
MOIST	VERY FRIABLE	VERY FRIABLE	VERY FRIABLE		
CEMENTATION			WEAK		
ROOTS ABUNDANCE	PLENTIFUL	FEW	VERY FEW		
DIAMETER	FINE	MEDIUM	FINE		
ORIENTATION	HORIZONTAL	HORIZONTAL	OBLIQUE		
DISTRIBUTION	INPED	INPED	EXPED		
SPECIES	HERBACEOUS	WOODY	WOODY		
CLAY FILMS - FREQUENCY		FEW	FEW		
THICKNESS		THIN	THIN		
CONCRETIONS					
FREE CARBONATES			MODERATE		
COARSE FRAGMENTS - SIZE		COBBLE	BOULDERS COBBLE		
ABUNDANCE		MANY	MANY		
pH	6.0	7.15	8.05		
DRAINAGE	IMPERFECTLY DRAINED				
BOUNDARIES WIDTH	ABRUPT	ABRUPT			
TOPOGRAPHY	WAVY	WAVY			

Figure 3-4

Profile diagram to accompany soil profile description in Table 3-3


SOIL TYPE A
PIT 3
LOCATION : JOHNSON NORTH
0
20
40
60
80
100
DEPTH (cm)
Ap
Bt
Ck

REMARKS :

- COMPACT SOIL BELOW 40 cm DEPTH
- NO ROOTS EVIDENT BELOW 80cm DEPTH

which time the root system will have fully exploited the available soil rooting volume, well below the plow layer.

Interpretation of Soil Survey Results

The rapid production of large quantities of biomass requires large amounts of water and an adequate supply of nutrients. It is possible to make some interpretation regarding the suitability of a soil to meet these requirements.

The shallow profile development, major gleyzation, and the poorly drained nature of the SNA 56 soil severely limits the volume of the soil available for rooting. Roots are confined to the upper 25 cm of soil. The acidic pH (5.7) observed in this soil has been associated with other failures of *Populus euramericana* plantations in eastern Ontario.

Domtar 1 is typical of many imperfectly drained soils in eastern Ontario. The soil is fine textured but well structured facilitating aeration. The compact lower portion of the soil profile slightly impedes root growth. The neutral to slightly alkaline pH is favourable for nutrient availability. The volume of soil available for root growth will be somewhat resticted until the roots are able to penetrate the compact lower soil profile. The water supply and nutrient levels appear to be adequate.

The imperfectly drained, medium to fine textured soil of Johnson North provides a good growing medium. However, the very compact nature of the lower soil profile impedes deep root development. Root growth will be initially restricted on this site until the compact

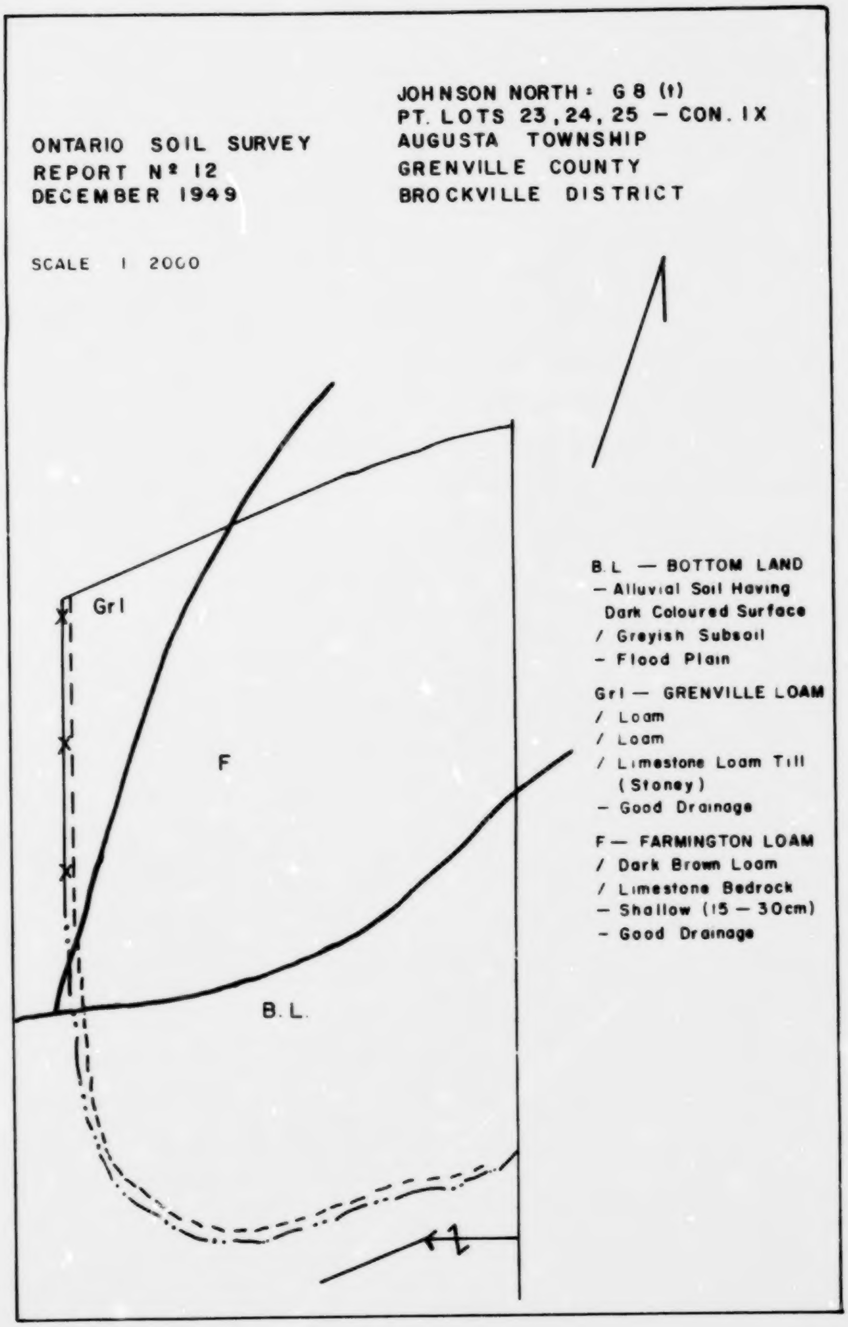
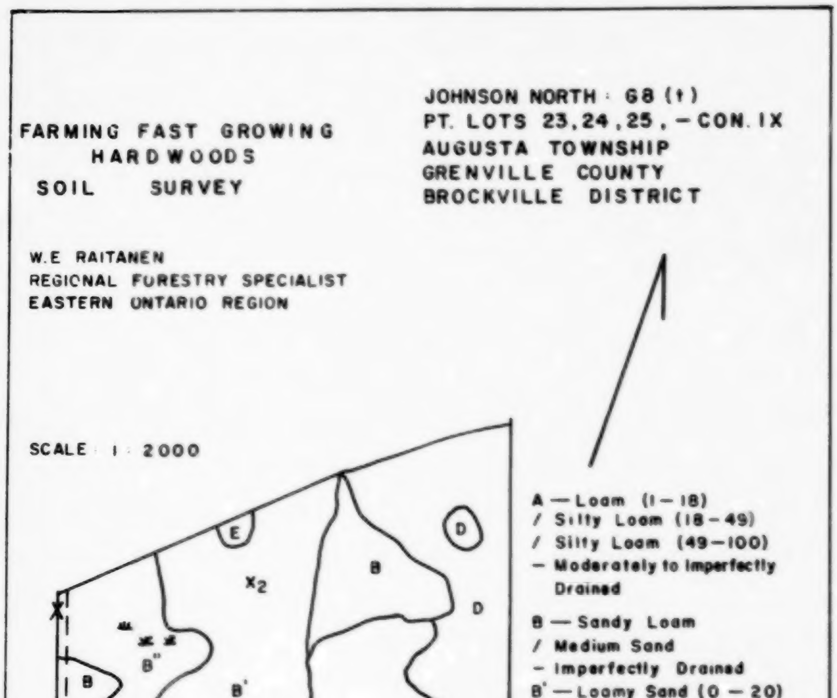

JOHNSON NORTH : G 8 (t)
PT. LOTS 23, 24, 25 — CON. IX
AUGUSTA TOWNSHIP
GRENVILLE COUNTY
BROCKVILLE DISTRICT
ONTARIO SOIL SURVEY
REPORT Nº 12
DECEMBER 1949
SCALE 1 2000
Grl
F
B.L.
B.L — BOTTOM LAND
— Alluvial Soil Having
Dark Coloured Surface
/ Greyish Subsoil
— Flood Plain
Grl — GRENVILLE LOAM
/ Loam
/ Loam
/ Limestone Loam Till
(Stoney)
— Good Drainage
F — FARMINGTON LOAM
/ Dark Brown Loam
/ Limestone Bedrock
— Shallow (15 — 30cm)
— Good Drainage

Figure 3-5

Soils of the Johnson North plantation as delineated by agricultural soil survey

Figure 3-6

Soils of the Johnson North plantation as delineated by intensive soil survey


FARMING FAST GROWING HARDWOODS
SOIL SURVEY
JOHNSON NORTH : 68 (t)
PT. LOTS 23,24,25, – CON. IX
AUGUSTA TOWNSHIP
GRENVILLE COUNTY
BROCKVILLE DISTRICT
W.E RAITANEN
REGIONAL FORESTRY SPECIALIST
EASTERN ONTARIO REGION
SCALE 1 : 2000
A — Loam (1 – 18)
/ Silty Loam (18 – 49)
/ Silty Loam (49 – 100)
– Moderately to Imperfectly Drained
B — Sandy Loam
/ Medium Sand
– Imperfectly Drained
B' — Loamy Sand (0 – 20)
/ Medium Sandy (20 – 39)
/ Silty Clay Loam (38 – 100)
– Well Drained
B'' — Grey Sand
– Poorly Drained
C — Clay Loam (0 – 30)
/ Silty Clay Loam (30 – 74)
/ Silty Clay Loam (74 – 100)
– Imperfectly Drained
D — Clay Loam (0 – 27)
/ Clay Loam (27 – 70)
/ Silty Clay (70 – 100)
– Imperfectly Drained
E — Loam
/ Sandy Loam
– Moderately Drained
E
D
X2
B
D
B''
B
B'
A
B
B
D
X4
A
X1
C
3X
E
E
D
A
D

lower soil is penetrated. The highly alkaline soil indicates an abundant supply of calcium.

The imperfectly drained, fine textured soil at Codrington provides for high rates of growth; the well structured soil aids aeration and ease of root penetration to a great depth. In a fine textured soil of this nature, the fertility levels can be expected to be high.

An Operational Soil Survey

As the area of plantings increases from less than 500 hectares per year to 1 000 hectares per year or higher, certain aspects of the soil survey will require modification. The present unit cost for the soil survey which includes preliminary stratification, mapping, pit excavation and a detailed profile description with pH analysis is $40 per hectare. A target cost of $25 per hectare should be attainable. Various cost reductions and increased operational efficiences can be realized by using special techniques such as supplementary aerial photography to prestratify the soil survey area.

The primary function of a soil survey as described by Armson (1977) is to "provide objectively determined quantitative and qualitative information about soils and their distributions in a given area. It may also provide certain interpretive information in relation to various uses but it should not do this at the expense of basic soil survey information." A sound soil survey, once completed, will provide the basis for a wide variety of future interpretations, at no additional cost to the forest estate.

Soils: The Basis for Investment Decisions

Accurate soils information is important in many management decisions and in scheduling day to day operations. The development of a site preparation prescription for a site depends on many operational considerations such as drainage, texture, consistency and stoniness. The type and amount of herbicide required for an area is partially governed by soil texture. Texture also strongly affects the behaviour of the chemical residue. Poorly drained areas may be greatly improved by constructing drainage ditches. Soils with serious fertility problems may require detailed soil analysis and special amelioration treatments. Poorer land may require additional inputs over those required for better quality sites. This may result in a reduced return on the investment, unless the costs of the additional inputs are balanced by a lower land cost. The most important use of the soils information is in the selection of the most appropriate genetic materials for planting on a given site. The best stock is required if the full productive potential of the site is to be realized. Implicit in this selection process is an understanding of the relationship between soils and the growth of different species and cultivars.

The decisions required in placing a particular clone on a specific site must be based on the application of all available, relevant information. Soil survey data, correlated with growth information from clone site trials, forms the basis for such decisions.

In the clone-site trials the clones are measured annually. The data are statistically analyzed and ranked to identify the most productive clones for each given set of soil conditions.

Generally, there are several top performing clones that do not differ significantly among themselves. These form a rank one grouping. Any clone from within this group can be planted on a similar site, with a known level of confidence of how it will grow.

Clone-Site Trials: Generating the Knowledge

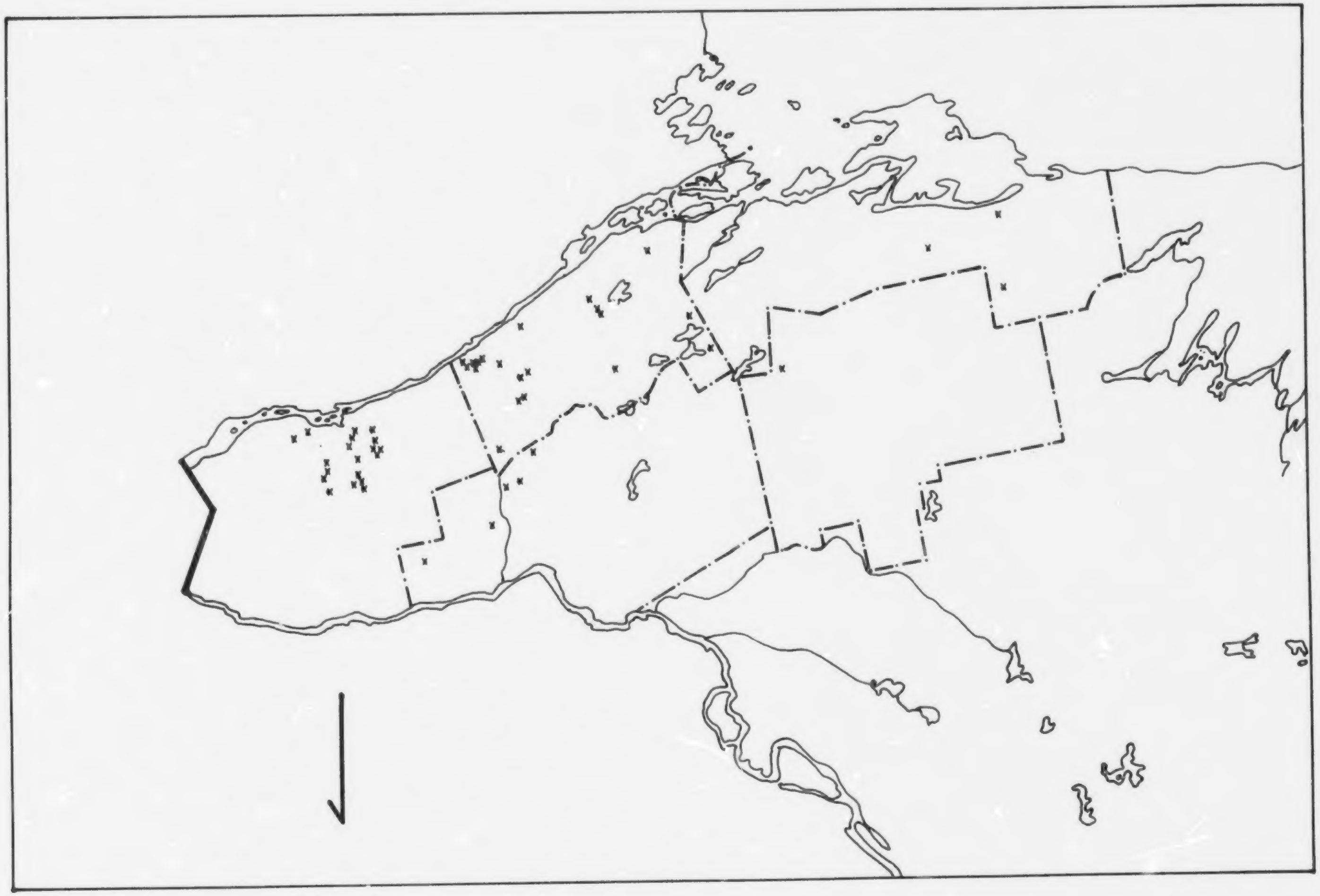
A number of clones are selected for testing on each site. Depending on the size of the testing site, 50 or more clones may be included in a trial. A randomized block design with three to five replications is commonly used, and a plot size of 25 trees has been determined to be statistically sufficient for this type of trial. Height, diameter and survival data are obtained annually. These data are subjected to analysis of variance and Duncan's multiple range test. The clones are then ranked, in descending order, for each parameter. The clonal ranking is used when deciding the most appropriate clone to be planted on a site.

In order to provide the necessary information base, clone-site trials must be established over a broad range of sites and locations. Figure 4-1 shows the distribution of clone-site trials throughout eastern Ontario. Each trial is located in an area which also has regular production plantings. Identical establishment procedures are used for both trial and production plantings. Thus, growth of clones in the trial occurs under normal field conditions.

Four clone site trials have been selected to typify clone site trials in eastern Ontario (Table 4-1). The soils vary from location to location (Table 4-2). The average heights of 'DTAC 1', 'DN 2', 'I-45/51', 'DN 17' and 'C 147' are shown in Figures 4-2, 4-3, 4-4, 4-5 and 4-6 respectively. In all cases the greatest average heights are being achieved on Domtar 8. A more complete picture of the differences in height growth between clones on the four different sites is provided in Figure 4-7. The average height at age four is used. It is evident that, for all but one clone in the test,

Figure 4-1

Distribution of clone site trials throughout eastern Ontario



Locations are indicated by X.

Table 4-1

Location, year of establishment and number of clones of four clone site trials

Property	Location	Year Established	Number of Clones
Domtar 7	St. Andrews West	1976	17
Domtar 8	Osnabruck Centre	1977	49
Johnson South	North Augusta	1976	17
Johnson North	North Augusta	1977	49

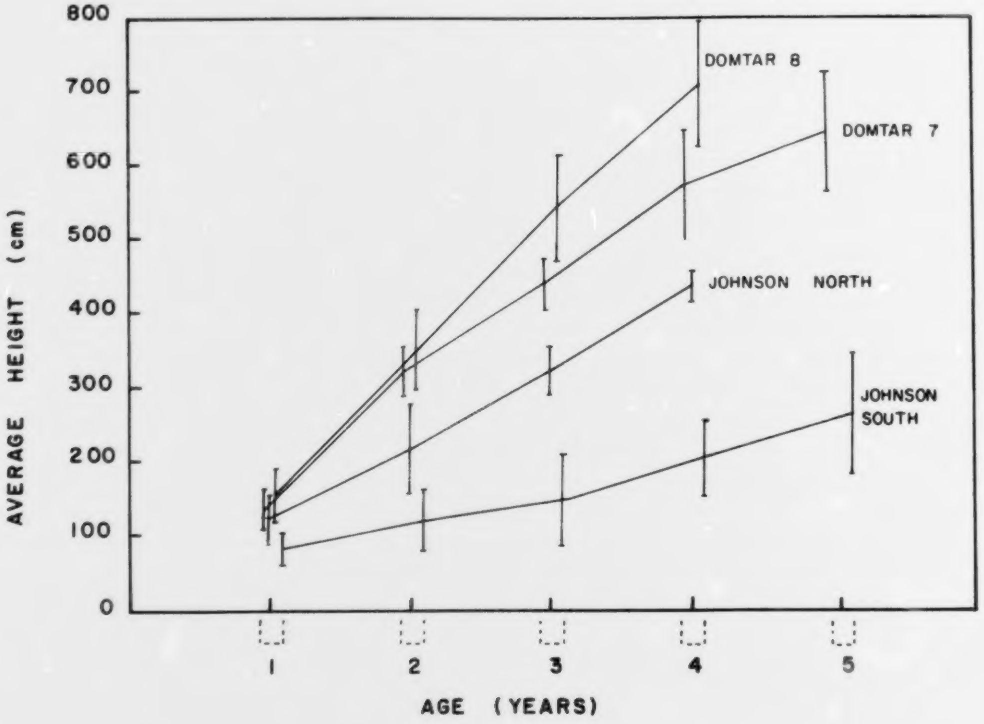
Table 4-2

Major soil characteristics of four clone site trials

Soil Characteristic	TRIAL			
	Domtar 7	Domtar 8	Johnson South	Johnson North
Texture:				
A Horizon	Clay Loam	Loam	Sandy Loamam	Sandy Loam
B Horizon	Clay Loam	Loam	Loam Sand	Sandy Loam
C Horizon	Loam	Silt Loam	Clay	Clay Loam
Drainage	Imperfect	Imperfect	Imperfect	Imperfect
Stoniness:				
Size and		Cobbles		Gravel
Abundance	None	Excessive	None	Abundant
Depth to C Horizon (cm)	84	85	50	45
pH	8.0	8.4	7.0	8.0
% Organic Matter	3	2	3	2

Figure 4-2

Comparison of average height over age for clone 'DTAC I' on four different sites



Vertical lines represent 95 per cent confidence limits.

Figure 4-3
Comparison of average height over age for clone 'DN 2' on four different sites

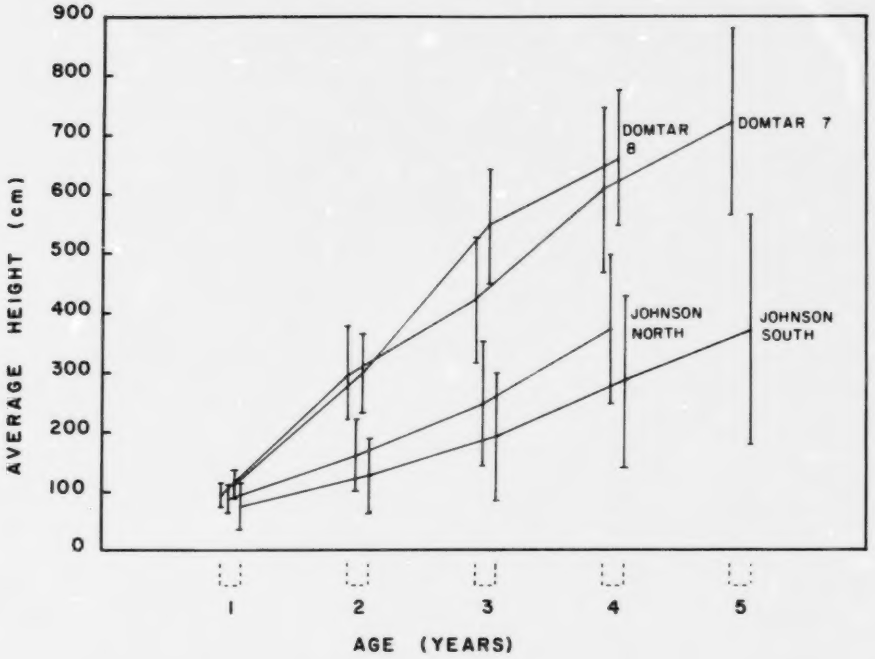
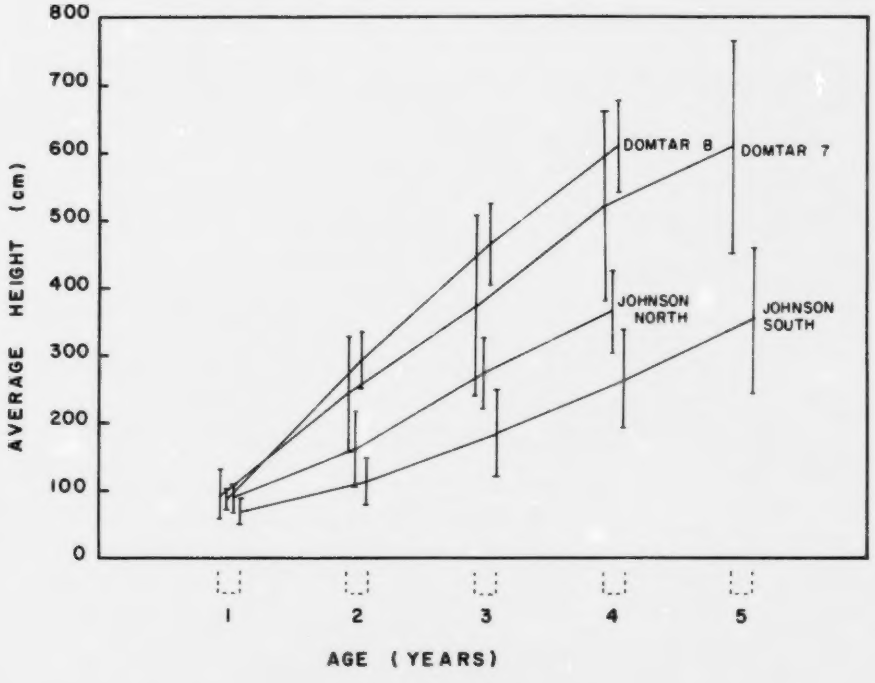


Figure 4-4
Comparison of average height over age for clone '1-45/51' on four different sites



Vertical lines represent 95 per cent confidence limits.

Figure 4-5

Comparison of average height over age for clone 'DN 17' on four different sites

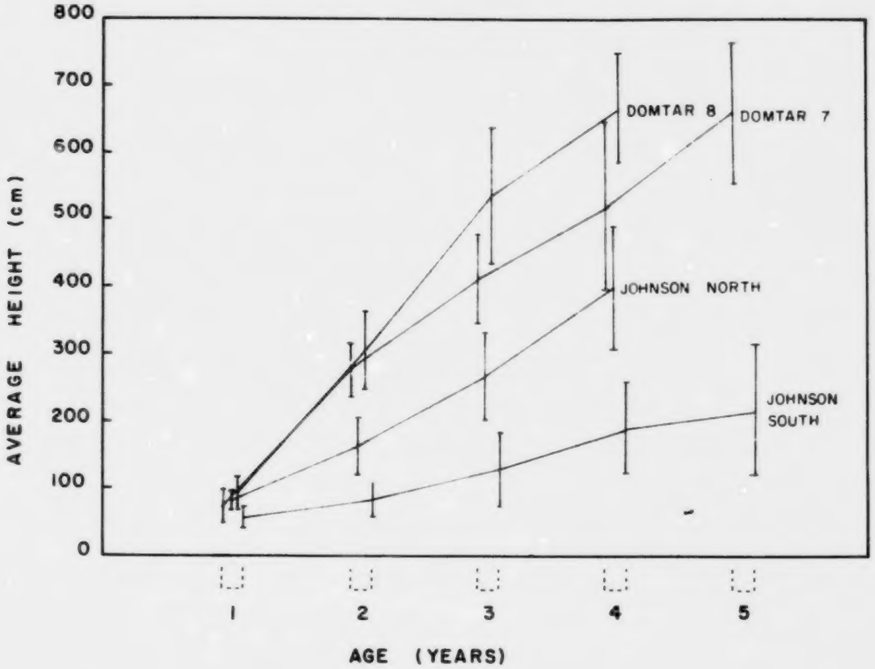
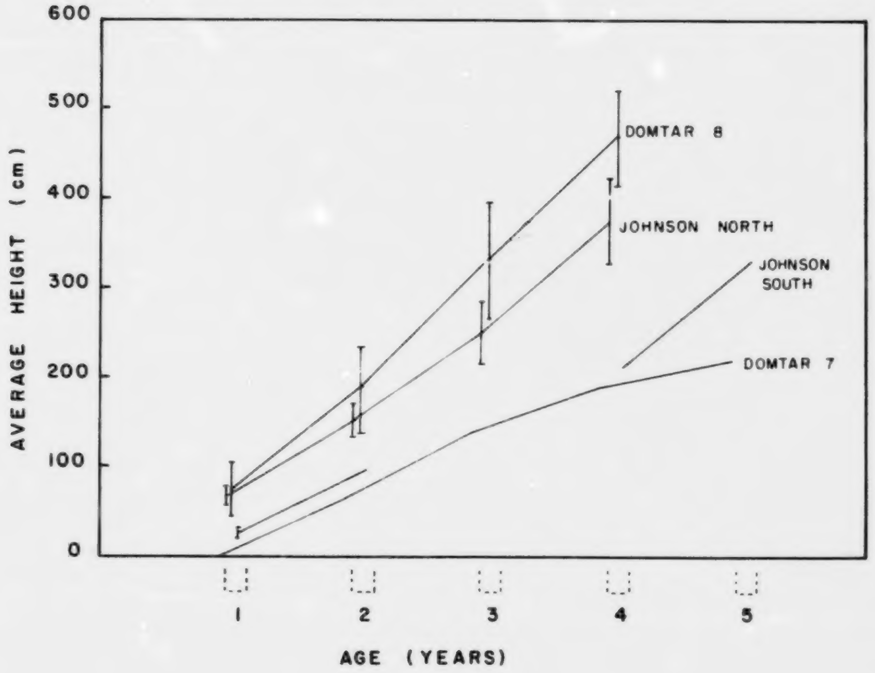


Figure 4-6

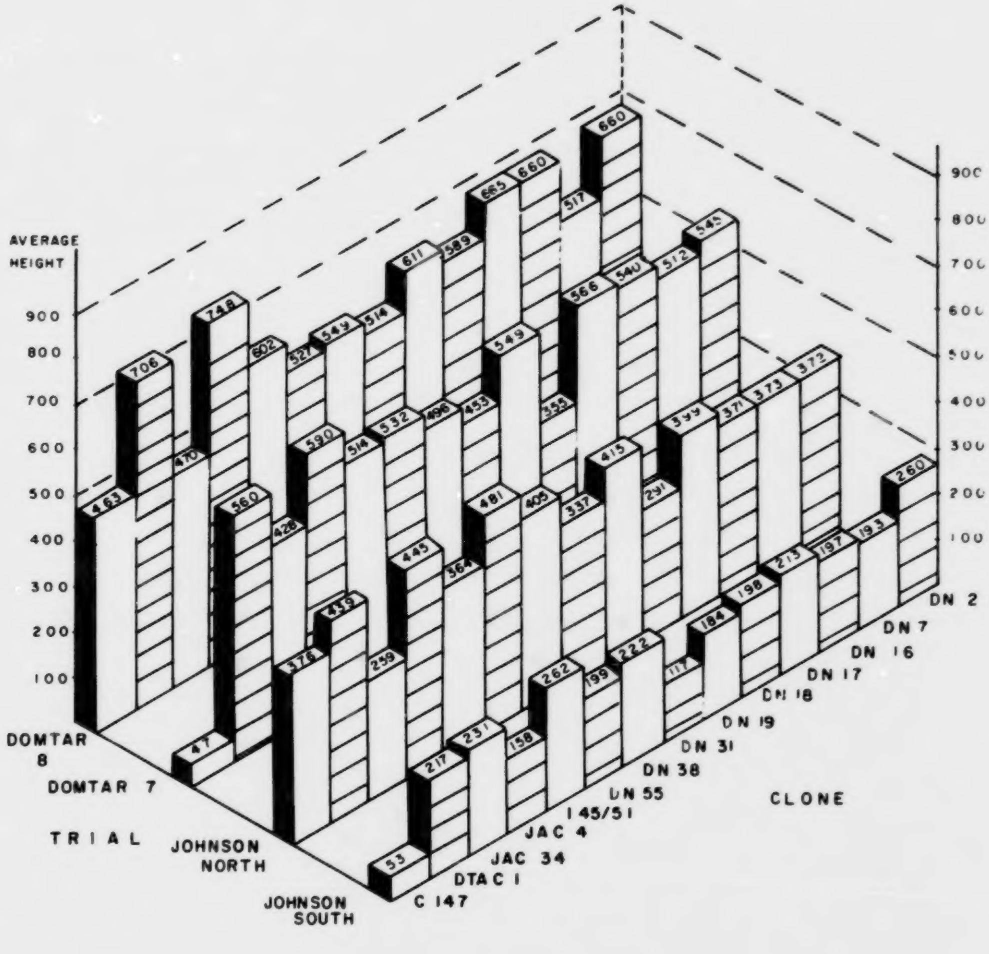
Comparison of average height over age for clone 'C 147' on four different sites



Vertical lines represent 95 per cent confidence limits.

Figure 4-7

Comparison of average height growth at age four of different clones on four different sites



Numbers give average height (cm) at age four years.

the greatest average height has been attained on the Domtar 8 site. Figures 4-8 to 4-11 show the relative position of fourteen clones common to all four trials on the basis of the cumulative height of all surviving trees in the plot. Cumulative plot height is selected as the growth parameter since it includes both growth and survival differences between clones. This measure may be particularly important for aspen type clones because these hybrids can grow rapidly on a given site, but the growth is often offset by the poor survival of unrooted cuttings which reduces the total amount of biomass produced. Tables 4-3 to 4-6 show the ranking of total plot height for the four clone site trials. Rankings are determined using Duncan's multiple range test. The rankings indicate that several clones are rank one and, therefore, equally suited for planting on this same site. In all four trials, shifting occurs over time in the relative positions of a number of clones. This is consistent with similar observations made by Zsuffa (1975).

Clone 'I-45/51' has been included in all clone site trials and tends to be an average grower on many sites. This clone is used as a standard against which the performance of other clones can be compared. Table 4-7 gives the average height for each clone at Domtar 8. Using Duncan's multiple range tests the clones can be segregated into thirteen ranks at the five per cent level of significance. However, when the average height the average height of each clone is expressed as a percentage of that of the standard, clone 'I-45/51', Duncan's multiple range test results in only two ranks. The larger number of ranks obtained by using the actual height measurements for Duncan's multiple range test provides more detailed information as to the expected

Figure 4-8

Cumulative height of all surviving trees in each plot over time, for different clones at Domtar 7

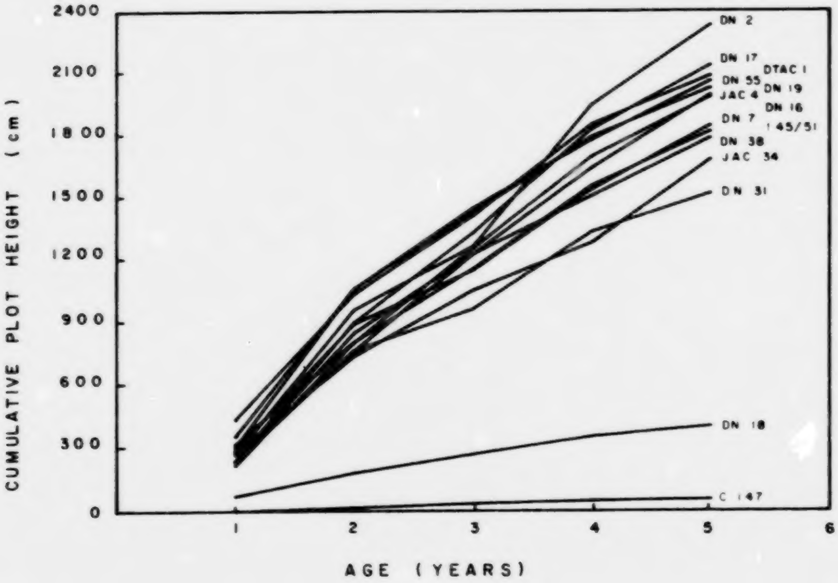


Figure 4-9

Cumulative height of all surviving trees in each plot over time, for different clones at Domtar 8

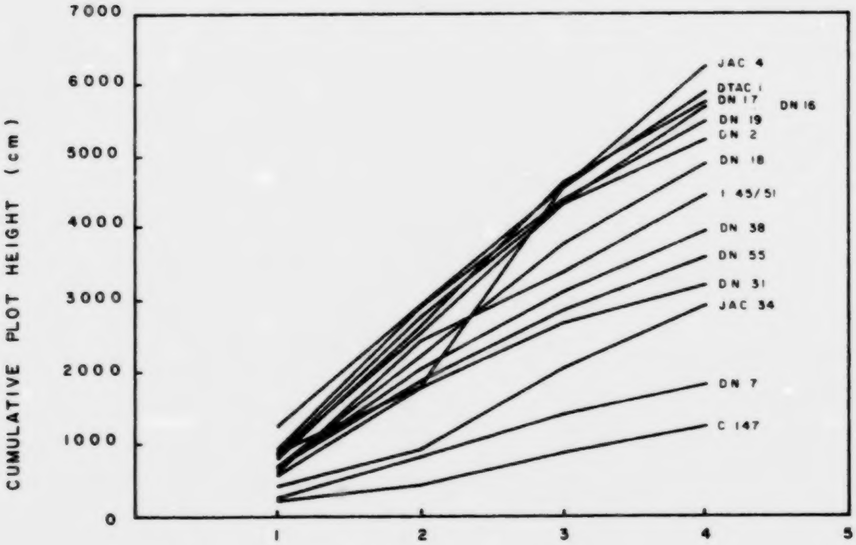


Figure 4-10

Cumulative height of all surviving trees in each plot over time, for different clones at Johnson South

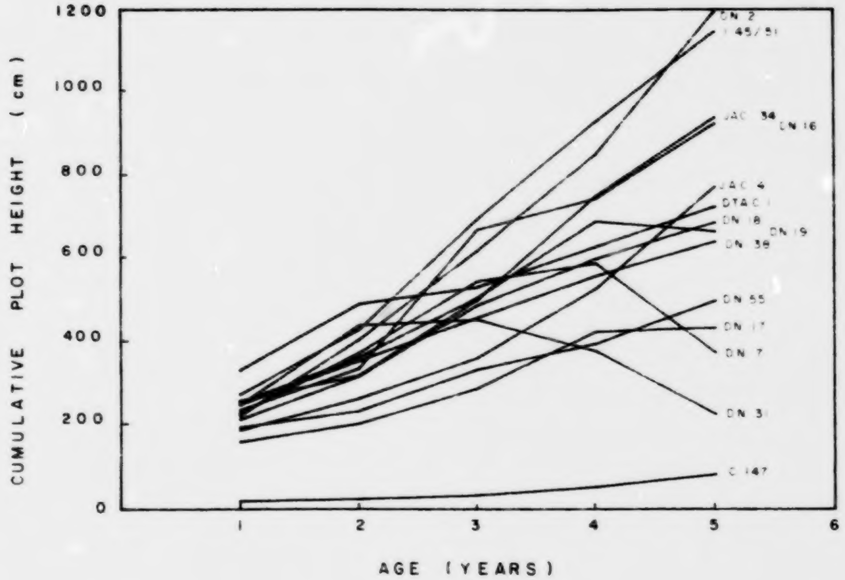


Figure 4-11

Cumulative height of all surviving trees in each plot over time, for different clones at Johnson North

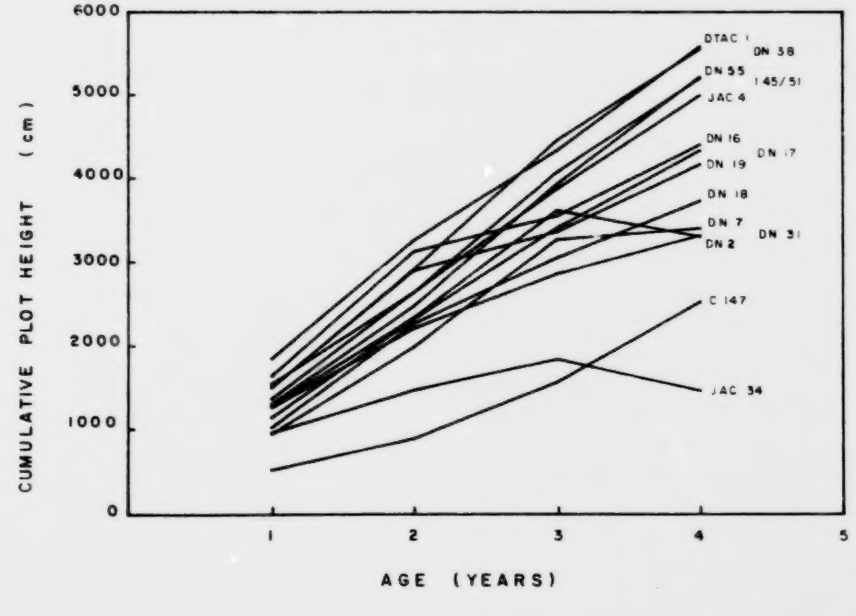


Table 4-3

Ranking of performance of different clones on the same site at Domtar 7

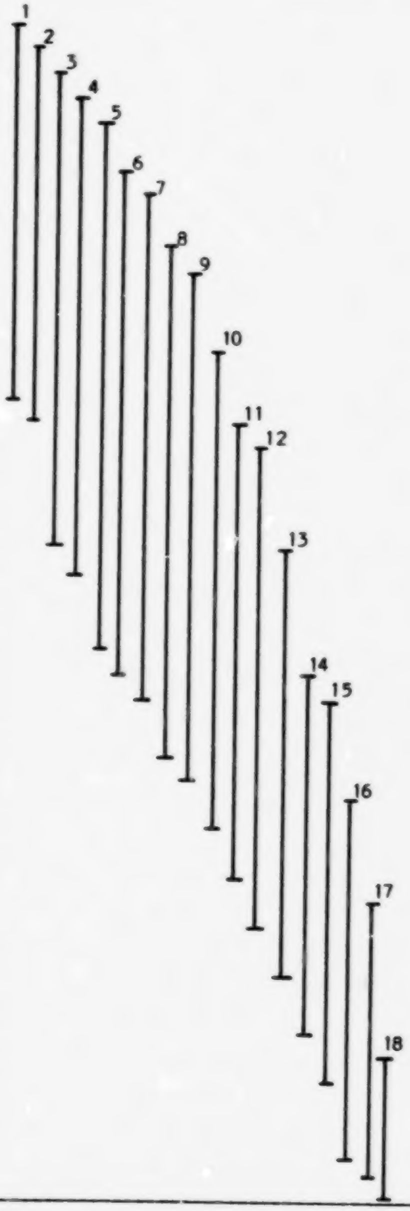
Clone	Mean Plot Cumulative Height (cm)	1	2	3	4	5
DN 2	2333	│				
DN 17	2138	│				
DTAC 1	2088	│	│			
DN 55	2063	│	│			
DN 19	2028	│	│			
JAC 4	1995	│	│			
DN 16	1985	│	│			
DN 7	1848	│	│			
1-45/51	1820	│	│			
DN 21	1803	│	│			
DN 38	1788	│	│			
JAC 34	1685	│	│			
DN 31	1523	│	│	│		
DTAC 4	1133		│	│	│	
AK 30	615			│	│	│
DN 18	405				│	│
C 147	55					│

Any two means not next to a common line are significantly different at the 5% level (Duncan's new multiple range test for significant differences).

Table 4-4

Ranking of performance of different clones on the same site at Domtar 8

Clones	Mean Plot Total Height (cm)
DN 1	6425
JAC 4	6268
DN 3	5960
DTAC 1	5905
DN 17	5772
DN 16	5703
DN 9	5500
D 38	5452
D 152	5355
DN 2	5242
1-214	5078
DN 6	5000
DN 133	4960
DN 8	4912
DN 74	4905
DN 104	4815
D 52	4623
DN 145	4495
1-45/51	4473
D 51	4472
DN 9	4393
DN 5	4372
DN 10	4325
DN 37	4218
D 138	4207
DN 38	3973
DN 70	3913
DN 33	3737
DTAC 2	3697
DN 55	3611
DN 56	3530
1-65 A	3368
DN 31	3222
DN 125	3110
DN 21	2983
JAC 34	2939
DN 28	2763
JAC 6	2762
DJAC 6	2388
AK 30	2341
DJAC 14	2310
D 37	2217
DN 7	1832
DJAC 15	1795
JACN 13	1250
C 147	1250
DN 25	510



Any two means not next to a common line are significantly different at the 5% level (Duncan's new multiple range test for significant differences).

Table 4-5

Ranking of performance of different clones on the same site at Johnson South

Clone	Mean Plot	Cumulative Height (cm)
DN 2	1195	1
1-45/51	1147	1, 2
JAC 34	940	1, 2, 3
DN 16	924	1, 2, 3, 4
DTAC 4	860	1, 2, 3, 4
JAC 4	774	1, 2, 3, 4, 5
AK 30	732	1, 2, 3, 4, 5
DTAC 1	725	1, 2, 3, 4, 5
DN 18	687	1, 2, 3, 4, 5
DN 19	665	2, 3, 4, 5
DN 38	641	2, 3, 4, 5, 6
DN 21	522	3, 4, 5, 6
DN 55	499	3, 4, 5, 6
DN 17	434	3, 4, 5, 6
DN 7	375	4, 5, 6
DN 31	228	5, 6
C 147	83	6

Any two means not next to a common line are significantly different at the 5% level (Duncan's new multiple range test for significant differences).

Table 4-6

Ranking of performance of different clones on the same site at Johnson North

Clone	Mean Plot	Cumulative Height (cm)									
		1	2	3	4	5	6	7	8	9	10
DTAC 2	7106	│									
DN 6	5892	│	│								
DN 37	5760	│	│	│							
DN 1	5753	│	│	│							
DN 3	5729	│	│	│							
DTAC 1	5575	│	│	│	│						
DN 38	5556	│	│	│	│						
DN 104	5299	│	│	│	│						
DN 19	5262	│	│	│	│	│					
1-45/51	5225	│	│	│	│	│					
DN 55	5206	│	│	│	│	│					
DN 104	5107	│	│	│	│	│	│				
AK 30	5004	│	│	│	│	│	│	│			
DN 74	4797	│	│	│	│	│	│	│	│		
DN 10	4750	│	│	│	│	│	│	│	│		
DN 28	5492	│	│	│	│	│	│	│	│		
DN 9	4549	│	│	│	│	│	│	│	│		
DN 33	4441	│	│	│	│	│	│	│	│		
DN 16	4417	│	│	│	│	│	│	│	│		
DN 17	4348		│	│	│	│	│	│	│		
DN 145	4333		│	│	│	│	│	│	│		
1-214	4252		│	│	│	│	│	│	│	│	
DN 138	4160		│	│	│	│	│	│	│	│	
DN 70	4140		│	│	│	│	│	│	│	│	
DN 5	4091		│	│	│	│	│	│	│	│	
DN 125	3977		│	│	│	│	│	│	│	│	│
DN 133	3972		│	│	│	│	│	│	│	│	│
D 38	3893		│	│	│	│	│	│	│	│	│
DN 18	3749		│	│	│	│	│	│	│	│	│
DN 56	3581		│	│	│	│	│	│	│	│	│
DN 25	3546		│	│	│	│	│	│	│	│	│
DN 7	3422		│	│	│	│	│	│	│	│	│
JAC 4	3406		│	│	│	│	│	│	│	│	│
DN 2	3338		│	│	│	│	│	│	│	│	│
DN 31	3323		│	│	│	│	│	│	│	│	│
DN 21	3061			│	│	│	│	│	│	│	│
1-65 A	2910				│	│	│	│	│	│	│
JAC 4	2885				│	│	│	│	│	│	│
C 147	2543					│	│	│	│	│	│
DJAC 6	2414						│	│	│	│	│
D 37	2307							│	│	│	│
DJAC 15	2213								│	│	│
JAC 34	1478									│	│
DJAC 14	1351										│

Any two means not next to a common line are significantly different at the 5% level (Duncan's new multiple range test for significant differences).

Table 4-7

Comparison of Duncan's multiple range test ranking with the ranking of clones relative to 'I-45/51' on Domtar 8

Clone	Average Height(cm)	Duncan's Ranking	% of the Average Height of 145/51
JAC 4	748	1	a 124.3
DN 1	743	1	a 123.4
DN 74	724	1	a 120.3
DTAC 2	718	1	a 119.3
DN 145	716	1	a 118.9
DTAC 1	706	1	a 117.3
D 152	693	1	a 115.1
DN 3	690	1	a 114.6
DN 138	675	1	a 112.1
DN 133	674	1	a 111.9
DN 17	665	1	a 110.5
DN 2	660	1	a 109.6
DN 16	660	1	a 109.6
D 52	656	1	a 109.0
165A	638	1	a 105.9
DN 33	636	1	a 105.6
DN 104	630	1	a 104.6
D 38	629	1	a 104.5
DN 6	620	1	a 103.0
DN 37	620	1	a 103.0
DN 19	611	1	a 101.5
I-214	610	1	a 101.3
DN 21	606	1	a 100.6
I-45/51	602	1	a 100.0
DN 9	600	1	a 99.7
DN 18	589	1	a 97.8
DN 56	587	1	a 97.5
DN 5	586	1	a 97.3
D 51	585	1	a 97.2
DN 125	576	2	a 95.7
DN 28	569	2	a 94.5
DN 10	565	2	a 93.8
DN 38	549	3	a 91.2
DJAC 6	541	4	a 89.9
DN 55	527	5	a 87.5
DN 7	517	5	a 85.9
JAC 6	517	5	a 85.9
DN 70	515	5	a 85.5
DN 31	514	6	a 85.4
D 37	485	7	a 80.6
JAC 34	470	8	a 78.1
C 147	463	9	a 76.9
JACN 13	453	10	b 75.3
AK 30	440	10	b 73.1
DJAC 14	418	11	b 69.4
DN 25	312	12	b 51.8
DJAC 15	239	13	b 39.7

The average height of each clone is expressed as a percentage of the average height of 'I-45/51'. Clones indicated by "a" are not significantly different from 'I-45/51' at the 5% level.

performance of a clone on a site. This additional information is of value when it is desired to increase the genetic diversity on a uniform site by planting several different clones. Variation in growth due to site differences is masked when clone 'I-45/51' is used as a standard for ranking since its growth also varies with the site. Thus, the use of one clone as a standard has a limitation.

All clone-site trials are evaluated annually for frost damage. As the trees become taller, frost damage becomes less frequent. The ranking of various four-year-old clones on Domtar 8 for susceptibility to frost damage is shown in Table 4-8. In the spring of 1981 'DTAC 2' was the only clone to show high levels of frost damage. Susceptibility to frost not only reduces growth but frost-killed tissue provides entrance courts for disease such as Cytospora chrysoperma (Pers.) Fr. Vigorous trees are usually able to overcome such infections. However, to avoid disease problems in younger plantations, clones susceptible to frost damage are not planted in areas with frost pockets.

Adaptations of Clones to Sites

It has been observed that the growth of different clones in clone-site trials will vary with soil conditions. Our understanding of the reasons for these changes in growth is limited. Differences in root structure between clones may partially determine the suitability of a clone for a particular site. The diagrams of the root systems of three different types of poplar growing on the same site (imperfectly drained loamy sand) show differences in structure. 'DN 22' shows a very well-developed deep root system which has thoroughly

Table 4-8

Susceptibility of various clones at four years of age to frost dmage at Domtar 8 clone site trial

Clone	% of Trees Damaged	Average Damage per Tree Length (cm) of Frost Killed Leader
	1	1
DTAC 2	36 2	43.2 2
DN 125	17 3	19.4 3
JAC 34	14	1.4
DN 28	13 4	1.4
DN 17	3	0.1
AK 30	0	0
C 147	0	0
D 37	0	0
D 38	0	0
D 51	0	0
D 52	0	0
D 152	0	0
DJAC 15	0	0
DJAC 6	0	0
DJAC 14	0	0
DN 1	0	0
DN 2	0	0
DN 3	0	0
DN 5	0	0
DN 6	0	0
DN 7	0	0
DN 9	0	0
DN 10	0	0
DN 16	0	0
DN 18	0	0
DN 19	0	0
DN 21	0	0
DN 25	0	0
DN 31	0	0
DN 33	0	0
DN 37	0	0
DN 38	0	0
DN 55	0	0
DN 56	0	0
DN 70	0	0
DN 74	0	0
DN 104	0	0
DN 133	0	0
DN 138	0	0
DN 145	0	0
DTAC 1	0	0
1-214	0	0
1-65A	0	0
1-45/51	0	0
JAC 4	0	0
JAC 6	0	0

Ranking of per cent of trees damaged is based on the percentage of trees in the trial which show frost damage. Average damage is the average length (cm) of main stem per tree, killed by frost.

exploited a large volume of soil (Figure 4-12). The Populus nigra L. (black poplar) clone shows a somewhat similar root system (Figure 4-13). It is characterized by having more sinker roots extended downward from lateral roots at some distance away from the tree. This type of root system would be capable of exploiting a wide soil area. The Populus alba L. (white poplar) root system is smaller and shallower than those of the other two (Figure 4-14). The fanned appearance of some of the sinker roots may be associated with the poor aeration in the Bg horizon. This clone may be better suited to sites with better drainage. The 'DN 22' root system appears to be tolerant of poor aeration. A better understanding of the relationship between clones and site will eventually facilitate better interpretation of the objective soil survey data when unknown sites are encountered.

Allocation of Clones to Site

Based on soil survey information, each planting site is subdivided into blocks of two hectares. Data from the soil survey of the proposed planting site and data on the clonal performance on different sites are used to determine the most suitable clones for each soil type. Although a number of the blocks may be of the same soil type, a different clone is allocated to each block. This allocation procedure results in a high level of genetic diversity in the plantation.

At present the allocation of clones to the site is carried out manually. However, the data could easily be analyzed by computer to produce a suitable clone allocation (Figure 4-15). Various operational research techniques could be used to develop an optimal clone

Figure 4-12

'DN 22' root system: Leitrim

Age: 10 yr.
Height: 15.17 m
Diameter (DBH): 26 cm
Scale: 1:10

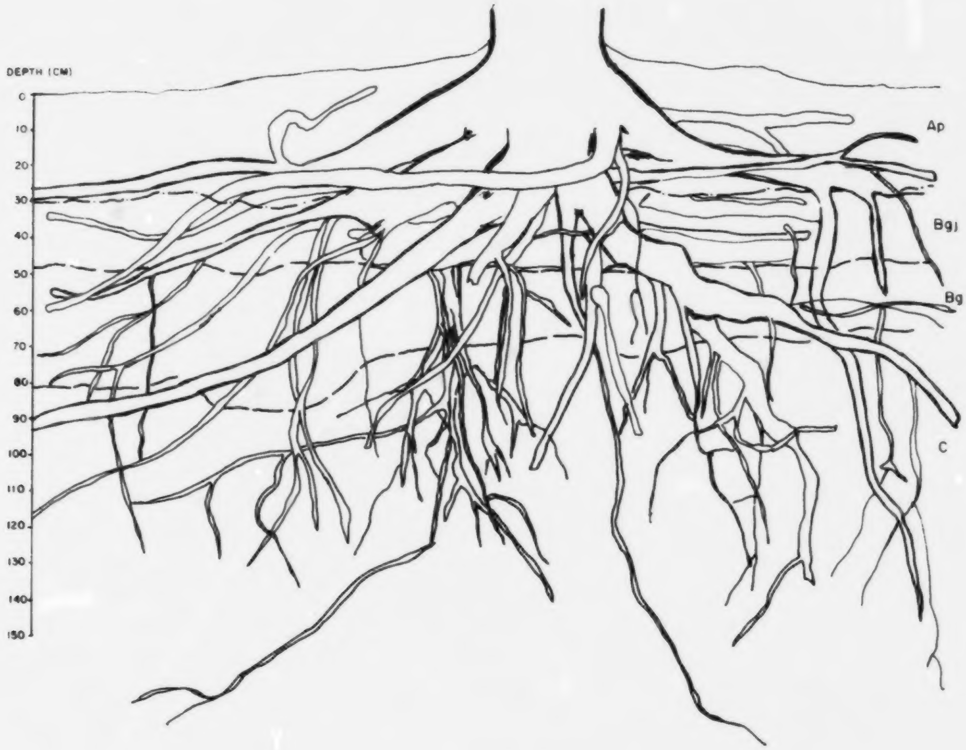

DEPTH (CM)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
Ap
Bgj
Bg
C

Figure 4-13

Populus nigra root system: Leitrim

Age: 10 yr.
Height: 14.37 m
Diameter (DBH): 20 cm
Scale: 1:10

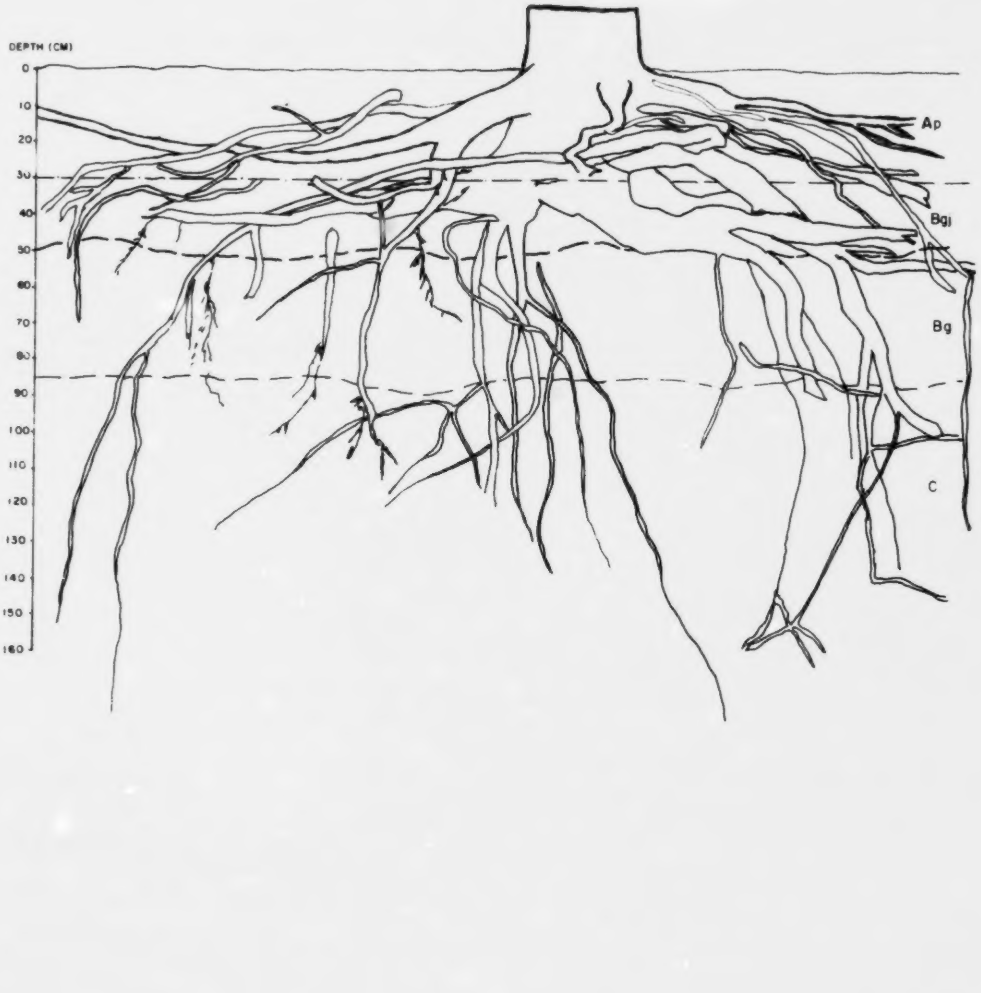

DEPTH (CM)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
Ap
Bgj
Bg
C

Figure 4-14

Populus alba root system: Leitrim

Age: 10 yr.
Height: 15.17 m
Diameter (DBH): 26 cm
Scale: 1:10

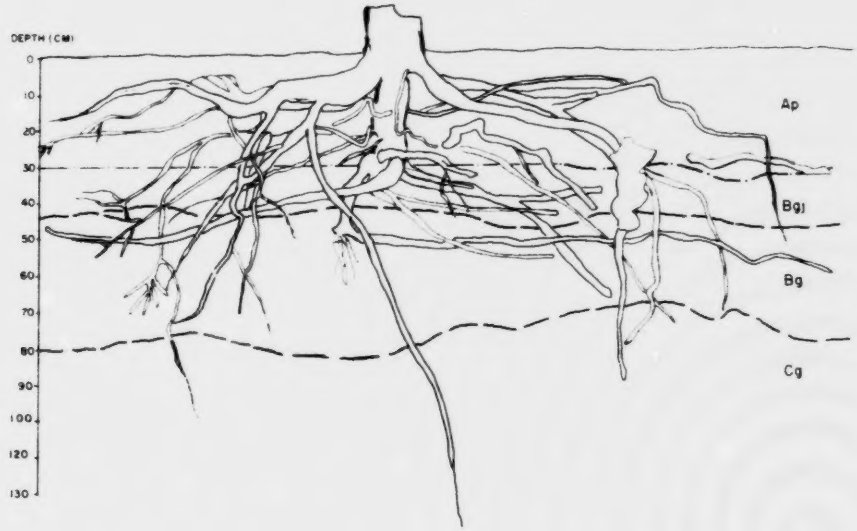
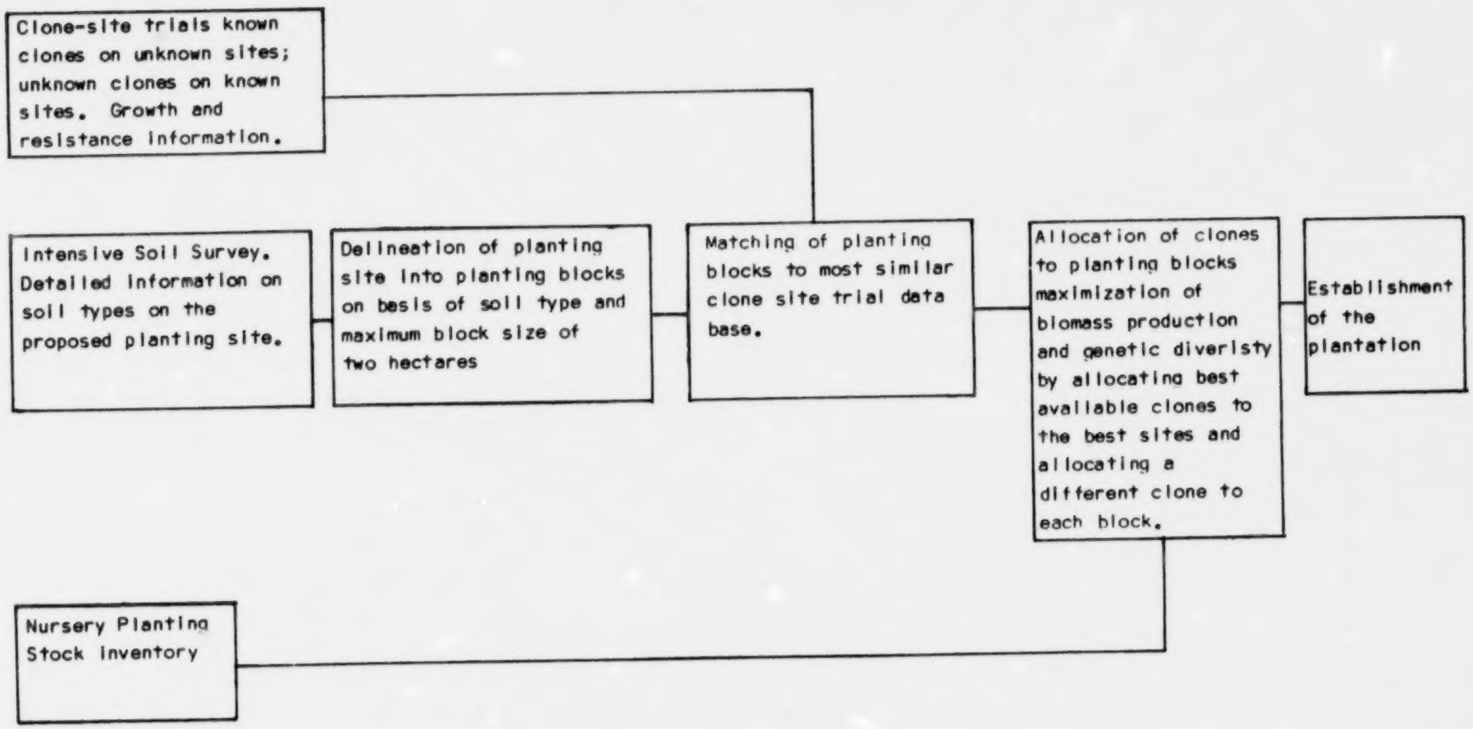

DEPTH (CM)
0
10
20
30
40
50
60
70
80
90
100
120
130
Ap
Bgj
Bg
Cg

Figure 4-15

Proposed procedure for clone allocation
as a basis for computer selection


Clone-site trials known clones on unknown sites; unknown clones on known sites. Growth and resistance information.
Intensive Soil Survey. Detailed information on soil types on the proposed planting site.
Delineation of planting site into planting blocks on basis of soil type and maximum block size of two hectares
Matching of planting blocks to most similar clone site trial data base.
Allocation of clones to planting blocks maximization of biomass production and genetic diveristy by allocating best available clones to the best sites and allocating a different clone to each block.
Establishment of the plantation
Nursery Planting Stock Inventory

allocation for maximum biomass production on a regional basis. This would ensure the most efficent use of the land base and the genetic stock available for planting. Constraints such as maximum planting block size for a single clone could be specified in order to build the desired level of genetic diversity into the allocation. As the size of the planting program increases, allocation by computer will become necessary.

5 NURSERY PRODUCTION OF FAST-GROWING HARDWOODS

The G. Howard Ferguson Provincial Tree Nursery at Kemptville is the largest producer of poplar planting stock in Ontario. In 1980, the nursery produced a total of 1.2 million poplar stock for the 1981 planting season (see Table 5-1). Unrooted cutting stock constituted 83 per cent of this total production. Since 1974, the nursery has been successfully developing the cultural practices required to produce the quality, quantity and wide range of stock required for production and trial planting programs.

This chapter describes the present production techniques and technology practiced at the Kemptville Nursery. The production of 1 million unrooted hybrid poplar cuttings will be emphasized. Rooted stock, seedlings and other vegetative stock production will be discussed by exception only.

Table 5-1

1980 fast-growing hardwoods production at Kemptville Nursery

Stock Type	Quantity in Thousands	Size	Comments
Unrooted cuttings	1,000	25 cm x 10-20 mm	poplar, willow
1+0 rooted	100	2.0 m	poplar
2+0 rooted	10	5-6 m	poplar
Seedlings (1 year)	100	0.5-1.5 m	G-1 transplants 300 populations
Vegetative propagules	4	0.5 m	propagation of 300 loplar selections
Total	1,214		

The Physical Plant - Framework of a Hybrid Poplar Nursery

The resources which form the physical framework of a nursery are of primary concern in the production of large quantities of planting stock. The quality and wide diversity of stock required by field planting programs place demands on the development, maintenance and improvement of nursery facilities. The main features of the nursery are:

- Land base (area requirements)
- Water requirements
- Site (soils, climatic information)
- Location (labour requirement, transportation, communications)
- Drainage requirements
- Cold storage facilities
- Equipment requirements
- Nursery layout for cutting production

Land Base Requirements

Ten hectare of land is required to produce 1 million cuttings per year; 8 ha in production and 2 ha in fallow as older cutting beds are replaced.

Water Requirements

Where irrigation is required to offset growing season moisture deficiencies, a reliable supply of quality water is required. The water source should be within close proximity of the nursery site.

The irrigation system at the Kemptville Nursery has the capacity to pump 2 700 litres/minute from a river

Table 5-2

Analysis of irrigation water at Kemptville Nursery

Parameter	Level
pH	7.6
Total dissolved solids (ppm)	230.0
Cations and anions (meq/l)	
Ca^{2+}	1.50
Mg^{2+}	1.85
K^{+}	0.04
Na^{+}	0.54
HCO_3^{-}	3.40
SO_4^{2-}	2.02
Cl^{-}	0.86

Source: Armson and Sadreika, 1979

adjacent to the nursery site. Each sprinkler covers a distance up to 18 m from the nozzle and delivers 2.5 cm of water over the area per hour. Table 5-2 summarizes the chemical constituents of the nursery water supply.

Site

Soils:

Comprehensive knowledge of the quality, variability and limitations of the nursery soil base is essential to successful nursery stock production. Table 5-3 outlines the optimal nursery soil and site conditions for poplar stock production. Table 5-4 summarizes the general soil conditions of the Kemptville Nursery.

Table 5-3

Poplar nursery:
desired soil-site conditions

Parameter	Remarks
Soil texture	Sandy loam; 20 - 25% silt and clay
Organic matter (O.M.)	5% or greater
Water Table (depth, m)	1.5 m (good under drainage)
pH	5.5 - 7.5
Grade	level (1 - 2% grade maximum)

Source: FAO, 1979

Table 5-4

Soil conditions at Kemptville Nursery

Soil Type	Texture	Moisture	pH	Organic Matter % d.wt.	Comments
Uplands sand	loamy sand over sand	well drained	5.8 to 7.0	2-4%	very rapid drainage
Rubicon sandy loam	sandy loam over sand	moderately well to imperfectly drained	6.2 to 6.0	4%	-
Granby sandy loam	sandy loam over sand	imperfectly to poorly drained	6.2 to 7.2	3-4%	tile drainage required

Source: Richards et al., 1949

Table 5-5

Climatic data, Kemptville Nursery

Annual growing degree days (Base 1°C)	2,489 days
Frost free days	197 days
Total mean precipitation	829 mm
Total rain	545 mm
Total Snow	284 mm
Mean Annual Temperature	6.2°C

Source: Adamo, 1981

Climate:

Local climatic information, combined with nursery soils data, is important in determining nursery cultural practices. Table 5-5 summarizes the pertinent climatic data of the Kemptville Nursery.

Location

Relevant factors important to setting the location of a nursery are:

- Proximity and availability of a labour force
- Regional access (i.e., central to the area serviced)
- Access to hydro and gas service
- Access to a nearby source of peat
- Access to suitable transportation routes

Kemptville Nursery is satisfactorily located with respect to all these features.

Drainage

Tile drainage may be required on wet sites to increase soil productivity and allow cultural practices over the entire growing season. The tile drainage system at the Kemptville Nursery consists of plastic tile spaced at 9.2 m centres and buried to an average depth of 1.0 m. Eighty per cent of the area under poplar is tile drained.

Cold Storage and Stock Processing Facilities

The cold storage facilities must be capable of maintaining a temperature of -4 C, with a maximum range in temperature of -1 C to -6 C. To store 1.0 million cuttings, a storage facility of 12 m x 15 m x 5 m is required. To facilitate cutting production in the fall, an open building 25 m x 25 m with a large receiving/shipping dock is necessary.

Equipment Requirements

Two specialized pieces of equipment are used at the Kemptville Nursery:

1. Balthes (registered tradename) extendable sprayer (2 m boom; 800 L spray tank), used for pesticide application in cutting beds where high clearance is required.
2. Pneumatic Cutting Head (tempered steel blade; automatic cutting head) used for processing cuttings.

Routine nursery equipment includes tractors, boom sprayers, trucks, fertilizer spreaders and hydraulic cutting shears.

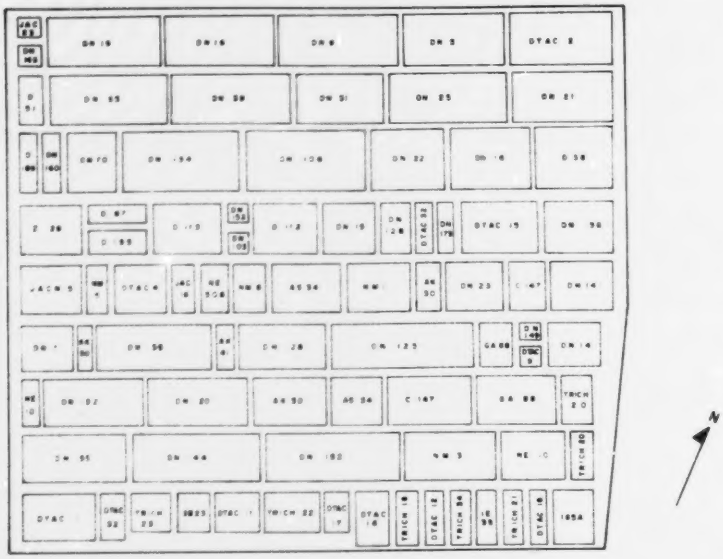
Nursery Layout for Cutting Production

Nursery compartments should be organized and laid out in order to maximize land use, maintain clonal integrity and be operationally efficient.

Figures 5-1 and 5-2 depict Compartment 71 at Kemptville Nursery. The following features should be noted:

Figure 5-1

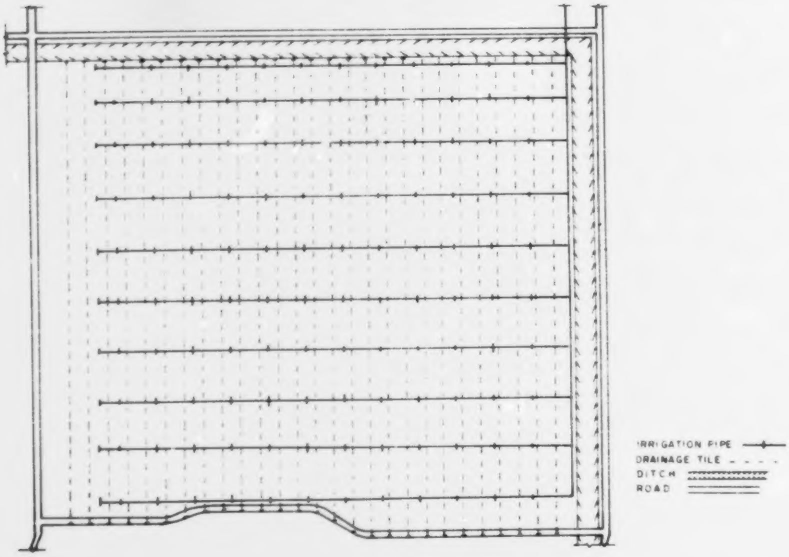
Compartment 71 layout of clonal blocks for hybrid poplar cutting production


JAC 83
DN 149
DN 19
DN 16
DN 9
DN 5
DTAC 2
D 51
DN 55
DN 59
DN 51
DN 25
DN 21
D 88
DN 160
DN 70
DN 154
DN 106
DN 22
DN 16
D 38
Z 28
D 87
D 155
D 119
DN 152
DN 03
D 112
DN 19
DN 128
DTAC 32
DN 178
DTAC 15
DN 38
JACN 5
NM 4
DTAC 4
JAC 6
NE 308
NM 6
AS 34
NM 1
AN 30
DN 23
C 167
DN 14
DN 7
AN 30
DN 58
AN 4
DN 28
DN 125
GA 88
DN 149
DTAC 9
DN 14
NE 10
DN 92
DN 20
AN 30
AS 34
C 167
GA 88
TRICH 20
DN 95
DN 44
DN 182
NM 3
NE 10
TRICH 80
DTAC
DTAC 32
TRICH 25
1823
DTAC 1
TRICH 22
DTAC 17
DTAC 16
TRICH 18
DTAC 12
TRICH 34
IE 38
TRICH 21
DTAC 16
185A
N

21 ROWS PER BLOCK
ROWS RUN EAST AND WEST

Figure 5-2

Compartment 71 layout of access, irrigation and drainage for hybrid poplar cutting production


IRRIGATION PIPE
DRAINAGE TILE
DITCH
ROAD

- Access (primary and secondary road system)
- Irrigation (18 m centres)
- Drainage (tile drainage, collection ditches)
- Clonal block dimensions and buffer corridors (takes into account minimum size areas and provides 3 m buffers for equipment mobility)

Complete documentation of compartment layout and of clonal block identity, age and cultural history is both mandatory and necessary for future reference.

Requirements for the production of 1+0 and 2+0 rooted stock do not differ from cutting production requirements, except as follows:

1. Total land requirements are 2.0 ha.
2. Cold storage facilities are not required since the material is heeled-in over winter.
3. Equipment requirements:
   (a) rototiller for weed control in 2+0 stock production
   (b) Egedal Side Lifter (registered tradename) (tractor-mounted lifter for rooted stock)
4. Rooted stock is planted out in lines, with a metal marker identifying the clone at the beginning and end of each line.

Cutting Production

Successful production of unrooted cuttings is a function of the intensity of nursery stool bed (cutting bed) management. The nursery manager must ensure optimal stool bed growth conditions to maximize cutting production.

Site Preparation

The timing and intensity of site preparation differs between open field and forested sites. Table 5-6 outlines the scheduling of site preparation for an old field and for a forest site. In both situations soil amendments may be required to increase the productivity of the site to desirable levels; these amendments are summarized in Table 5-7. Soil samples taken a year prior to planting should be analyzed for organic matter, phosphorus, potassium, calcium, magnesium, cation exchange capacity and pH to determine the level of amendments which may be necessary.

Planting

Planting at Kemptville Nursery normally begins in mid-April, as soon as the frost is out of the ground. Three types of cuttings are used for planting:

- Production cuttings
- Mini-cuttings
- Greenwood cuttings

Table 5-8 summarizes the characteristics of each type of cutting.

Cuttings are planted, at 1.0 m x 0.5 m spacing, using a hand dibble, or a two or three row, narrow trench, mechanical planter. Each individual clone is planted in a discrete block marked at each corner by a metal identification stake. Extreme care is taken to ensure the highest quality cutting stock is used for stool bed establishment.

Table 5-6

Scheduling of site preparation in year prior to planting

Activity	Season	Initial Stand Condition Field	 Forest Stand
Clear cut	Fall		x
Root extraction	Fall		x
Levelling	Fall	x	x
Roundup @ 2.2kg a.i./ha*	Spring	x	x
Plough to 25cm	Spring	x	
Discing	Late Spring	x	
Tile Drainage and Ditching (where required)	Summer	x	x
Peat (organic matter)addition (see Table 5-7)	Summer	x	x
Cultivation	Summer	x	x
Soil amendments (see Table 5-7)	Summer	x	x

* Roundup is a trademark for glyphosate manufactured by Monsanto

Table 5-7

Site preparation soil amendments commonly used at Kemptville Nursery

Parameter	Optimal Levels	Amendment
Organic matter	5.0% OM	Addition of peat (to 20 cm depth) (700 m^3 peat/ha to raise OM 1%)
Phosphorus	30.0 mg/100 g	Triple super phosphate (rate based on soil analysis)
Calcium	11.0 meq/100 g	Limestone additions
Potassium	0.30 meq/100 g	Potassium sulphate @112 kg/ha increases K 0.04 meq/100 g
C.E.C.	10.0 meq/100 g	addition of organic matter (increase OM 1% increases CEC 2 meq/100g)
pH	5.5-7.3	dolomitic limestone to increase pH (112-170 kg/ha of lime to raise pH by 0.1 unit)*
Magnesium	3.0 meq/100 g	112 kg/ha magnesium sulphate increases Mg 0.04 meq/100 g

* After Armson and Sadreika, 1979

Table 5-8

Cutting stock specifications

Characteristics	Cutting Type		
	Production Cutting	Mini Cutting	Greenwood Cutting
Physiological conditions	Dormant	Dormant	Actively growing
Storage Conditions	Frozen (-3°C)	Frozen (-3°C)	Perishable - must be kept actively growing
Size:			
length	25cm	7.5 cm	Variable
diameter	10 - 20 mm	N/A	Variable
Use	production planting	rapid propagation of valuable genetic material available in very limited amounts	Propagation of special genetic stock i.e., plus trees, rare clones, propagation of poor-rooting genetic material

Tending

Cultural tending practices are employed throughout the growing season to maximize the production of cutting material from the clonal stool beds. Tending practices include:

- Weed control
- Fertilization
- Pest control
- Irrigation

Table 5-9 outlines the growing season tending schedule for an established stool bed area. For greater economical and cultural efficiency, an expanded use of chemical weed control is anticipated. Current weed control practices are largely manual due to the limited amount of nursery chemical weed control technology available.

Production of 1+0 and 2+0 Rooted Stock

The cultural practices employed in rooted stock production do not differ greatly from those of cutting stock production. These differences are highlighted in Table 5-10.

The nursery manager must ensure that the clonal identity of each block is strictly maintained. If the identity of any one particular block or individual tree within the block is in question, the block or tree(s) must be removed. Complete documentation of all cultural input into each particular block/compartment is mandatory.

Table 5-9

Tending schedule at Kemptville Nursery
(All rates are per hectare unless otherwise stated)

Activity	Total Rate For Growing Season	Comments
Fertilizer		
Ammonium Nitrate	200 kg	Several applications (ending late June) by irrigation system
Potassium Sulphate	170 kg	3 applicationd (ending mid-July)(agricultural fertilizer spreader)
Monoammonium Phosphate	112 kg	Apply in second year before bud break
Weed Control		
(a) Herbicide		
Enide+Dacthal*	9.8 Kg+9.8 Kg	boom spray by mid-May
Roundup*	2.2 Kg	before stool leaf flush (grass control)
(b) Manual Weeding	N/A	throughout the growing season
Pest Control		
Malathion	1.4 L	prophylactic treatment every 1-2 weeks (boom spray)
Irrigation	1.5-2.0 cm irrigation every 3-4 days	maintain compartments between field capacity and 1 bar matrix tension (none after late July) (see Figure 5-4)

* Enide is a trademark for diphenamid, manufactured by UpJohn. Dacthal is a trademark for D.C.P.A., manufactured by Diamond Shamrock. Roundup is a trademark for glyphosate, manufactured by Monsanto.

Table 5-10

Cultural practices for 1+0 and 2+0 production at Kemptville Nursery

Activity	1+0 Production	2+0 Production
Site Preparation	same as cutting production	same as cutting production
Planting:		
Planting stock	unrooted cuttings	unrooted cuttings
Spacing	1.0 m x 0.1 m	1.0 m x 0.5 m
Block size	1 line, marked at both ends	1 line, marked at both ends
Tending:		
Fertilizer	same as cutting production	same as cutting production
Weed control	same as cutting production	1st year-same as cuttings 2nd year-manual and rototiller
Pest control	same as cutting production	same as cutting production
Irrigation	same as cutting production	same as cutting production
Pruning	not required	prune lower 1/2 stem in late summer of 2nd year; prune all remaining branches Fall 2nd year
Lifting	spring (Egedal lifter)	spring (Egedal lifter)
Shipping	spring	spring

Harvest to Shipping

Harvesting

The harvesting of whips for cutting production is done in the fall, immediately after leaf fall. Harvesting involves the manual cutting of all stems on the stool as close to the ground as possible. Manual or hydraulic shears are used. Table 5-11 outlines the relative productive capacity of cutting stool beds at the Kemptville Nursery. Actual production data are given in Table 5-12.

Processing and Storage

Stems are treated in the following manner:

- All stem side branches are pruned flush with the stem.
- Stems are automatically cut into 25 cm lengths with a pneumatic cutting head and placed on a conveyor belt.
- As the cuttings pass along the conveyor belt they are graded into small (<10 mm in diameter), medium (10 to 20 mm) and large (>20 mm) sizes. When clonal stock is available in limited quantities, small grade cuttings are retained; otherwise, the small cuttings are discarded. Bundles of 25 cuttings are prepared to facilitate packaging and inventory.
- The upper ends of the cuttings are painted to aid field planting checking.
- The cuttings are packed in heavy gauge plastic bags with damp peat moss and placed in waxed cardboard boxes (capacity: 500 cuttings per box). Each box

Table 5-11

Stool cutting production at Kemptville Nursery

Age of Stool (years)	Production
1	no crop
2	3/4 crop
3-6	full production
7	replace stool

Table 5-12

Cutting production in a two-year-old stool bed at Kemptville Nursery*

Clone	Number of Stools	Number of Cuttings per Stool	Number of Cuttings per ha (in thousands)
AS 34	1464	15.7	769
GA 88	2086	9.1	335
C 147	2289	7.3	276
D 38	1519	8.7	318
D 195	317	5.6	225
DN 3	135	19.4	878
DN 5	1809	5.7	211
DN 7	797	11.3	413
DN 9	1349	5.9	216
DN 18	1609	9.6	352
DN 19	1223	15.3	412
DN 20	3471	11.8	418
DN 21	981	16.7	600
DN 22	1432	11.7	431
DN 25	1362	11.0	397
DN 28	1052	12.2	498
DN 30	311	11.2	437
DN 31	822	12.3	472
DN 33	3976	11.3	411
DN 36	3138	16.5	715
DN 38	1293	17.7	662
DN 55	171	16.2	693
DN 170	695	16.2	593

* Medium and large cuttings (greater than 10 mm in diameter; 25 cm length). 1980 data.

is labelled as to clonal identity, cutting size, quantity and planting destination.

- The boxes of cuttings are stored in cold storage facilities for the winter.

Shipping

Boxes of cuttings are shipped by truck in March and April to cold storage facilities in the various districts, close to the planting sites.

Fast-Growing Hardwoods Seedling Production

Since 1975 over 500 different seedlots have been tested in eastern Ontario.

Propagation Techniques - Small Seedlots of Unknown Viability

1. The seed is broadcast in a well-drained tray and covered lightly with vermiculite.
2. The seeded tray is held in a greenhouse facility at 20 to 25° C and misted regularly.
3. After adequate germination has occurred, the frequency of watering is reduced.
4. After primary leaf development, the seedlings are transplanted into 96-cavity "cell-pak" trays (1:1 mixture of peat and vermiculite).
5. Fertilization through the irrigation system begins during the first two weeks with 10-52-10 water soluble fertilizer at the rates of 62 ppm N, 141 ppm P, and 52 ppm K. After two weeks, 20-20-20 is applied at rates of 120 ppm N, 53 ppm P and 98 ppm K.

6. Seedlings are outplanted into nursery beds after 10 weeks in the greenhouse and when the danger of spring frost is remote.

Propagation Techniques - Large Seedlots of Known Viability

1. Seeds are placed in 1.5 cm square cavities of a "waffle board" by a precision "Blackmore" seeder.
2. The seeded waffle boards are placed in the greenhouse, maintained at 20 to 25°C and misted liberally until germination is complete.
3. After primary leaf development, the seedlings are transplanted into larger cavities of the 96 cavity "cell pak" trays.
4. Seedlings are outplanted into the nursery beds after 10 weeks in the greenhouse, when the danger of spring frost is remote.

Vegetative Propagation of the Native Gene Pool

At Kemptville Nursery, procedures have been developed to vegetatively propagate native aspen, balsam and cottonwood selection material. Several propagation techniques have been developed to ensure the successful propagation of clonal material from each selection. Table 5-13 summarizes the suitability of each propagation technique to the vegetative reproduction of the four native eastern Ontario poplar species. The propagation work at Kemptville confirms general experience in propagation of these species.

Table 5-13

Vegetative propagation techniques for native *Populus* selections

Species	Root Sections (green shoots)	Bottle Grafts (green shoots)	Stem Cuttings
P. deltoides	2	2	1
P. balsamifera	1	2	2
P. grandidentata	1	2	3
P. tremuloides	1	2	3

1 - most successful method of propagation

2 - adequate method of propagation

3 - not suitable for species

Propagation of Green Shoots from Root Segments

Root sections 1 cm to 8 cm in diameter are placed in plastic trays with vermiculite and covered to a depth of 1 cm from the top of the root. Shoots develop along the root in two or three weeks. When the shoots grow to a height of 8 cm to 12 cm they are severed with a sharp blade and set into a perforated container filled with vermiculite. The container is placed in a water bath (to 1 cm in depth) and maintained at a temperature of 28 to 30 C. Within two weeks, roots develop on the cuttings. Rooted cuttings are transplanted into 4 L pots filled with a prepared soil mix and are grown in the greenhouse. The propagules are constantly cut back to produce more green shoots for propagation.

Propagation of Green Shoots from Branch Segments

Branch material is grafted onto potted understock. Green shoots develop and are severed from the successful bottle grafts. The plants are rooted as described above.

Production of Stem Cuttings

Stem cuttings 8 cm to 12 cm in length are prepared from one- to two-year-old branch material. The cuttings are propagated as specified in the treatment of root sections.

The Clonal Archives

After the successful propagation of 12 or more plants of each selection, a clonal archive (seed orchard) is established at the nursery to provide a secure area for future breeding of clonal stock. The trees are planted at relatively wide spacings (e.g., 6.0 m x 6.0 m) in a randomized block design. The trial design allows statistical analysis of the performance of the several hundred clones planted in the archive. The management of the archives is the same as for other nursery production areas.

Stock Production - Yield

Observations over two years of stool bed management in Compartment 71 indicate the following trends in stool survival over time:

1. The average survival rate in stools one year after establishment is 80 percent. Stool mortality is attributed mainly to low quality and small size of stock and unfavourable microsite conditions.
2. Mortality two years after establishment is extremely variable.

Costs of Stock Production

Table 5-14 summarizes the cost of planting stock produced at the Kemptville Nursery in 1979-80. The cost kigures include all variable costs (equipment, facilities, etc.) but do not include fixed overhead costs.

Table 5-14

Nursery stock costs, Kemptville Nursery (1979 - 80)

Stock	Production Costs ($/M)	Shipping Costs ($/M)	Total Cost ($/M)
Conifer			
2+0	14.77	18.93	33.70
3+0	19.75	28.40	48.15
1+2	174.76	18.93	193.69
2+2	162.01	47.34	209.35
Hardwoods			
1+0	24.92	43.50	68.42
2+0	28.75	65.26	94.01
Hybrid Poplar			
Cuttings	145.00	5.00	150.00

In the future, it is expected that hybrid poplar production costs, and in particular, cutting production costs, will be reduced by improved technology and increased stool bed yields.

The growth and production of individual stools varies by clone, age, site, response to cultural practices, environmental conditions and the impact of pest infestations. Table 5-12 summarizes the 1980 production of unrooted cuttings from 23 clones growing in a two-year- old stool bed at Kemptville Nursery.

Future Nursery Production of Fast-Growing Hardwoods

The fast-growing hardwoods production practices at Kemptville Nursery have proven successful to date, but there remain ample opportunities for improvement.

Cultural Technology Refinement

Although the majority of cultural practices employed at the nursery are effective, the reasoning or justification for their practice is more traditional or intuitive rather than scientific. The most graphic example of this is the scheduling and rate of application of fertilizers and irrigation. These have been based largely on the results obtained for conifer seedling production. Chemical weed control technology is urgently required to reduce the relatively large amounts of money and time spent in manual weeding.

Fall Lifting and Planting of Rooted Stock

The technology needed to lift and plant rooted stock in in the fall rather than the spring must be developed.

Fast-Growing Hardwood Inventory Techniques

The 1981 production of G-1 transplant stock (seedlings started early in the greenhouse and then transplanted to the nursery bed for one year) represents 100,000 trees from approximately 300 different seedlots. This stock is destined for field trials, and as such, extremely accurate inventory information is required for trial design considerations. Inventory techniques have to be developed to provide an improved level of accuracy.

Elimination and Addition of Clones at the Nursery Stage

As new and improved genetic material is entered into the eastern Ontario program, poorly performing clones will be removed from the production planting program. Unsuitable clones will be removed from nursery production at regular intervals to create stool bed areas for new genetic material as experience and knowledge are gained on clonal performance and pest and frost susceptibilities.

6 SETTING OUT THE CROP

Weed control is critical to the establishment of any crop. This is the final phase of the sequence of establishment operations which began with the choice of site, cultivation and planting. The degree of weed control actually achieved will determine in large part the success or failure of the stand.

Weed control must be maintained until the stand is free-to-grow. This condition is reached when the stand "is above the minimum stocking standard and is judged to be essentially free from competing vegetation" (Armson, et al., 1980). The free-to-grow judgement must be made for each stand; it cannot be generalized. The judgement must take into account the current annual increment of the crop under consideration and the growth and vigour of the competing vegetation. In the eastern region of Ontario, fast-growing hardwood stands normally reach the free-to-grow category within three years. Some stands with exceptional growth may attain this category in two years.

Weed control is expensive. This is especially true in high density stands. Therefore, the most cost effective treatments must be determined.

In work completed for the International Energy Agency, weed control methods have been reviewed (Raitanen, 1980). These methods included: biological control, cover cropping, fire, flooding, herbicides, mulching, shade and spacing, sod culture, soil fumigation and tillage. Only herbicides showed possibilities for broad application over a wide range of sites in an efficient manner, particularly in terms of manpower and equipment.

The efficacy of herbicides may be affected by soil properties. For example, the greater the cation exchange capacity, the greater the level of absorption of herbicides. Absorption plays a major role in herbicide degradation by helping to catalyse the degradation. Once absorbed, herbicides may be released so slowly as to be ineffective (Kingman and Ashton, 1975). Medium and high levels of pH favour bacterial degradation of herbicides. Bacterial action is inhibited below a pH of 5.5 (Kingman and Ashton, 1975). When water moves down the soil profile, herbicide leaching may occur. Herbicides are more mobile within the soil than either pesticides or fungicides (Kingman and Ashton, 1975). Conditions of either very good or very poor aeration are not conducive to microbial action and will allow herbicides to persist in the soil. (Kingman and Ashton, 1975). The triazines are less readily broken down by microbial action and are usually chemically degraded (Brady, 1974).

The use of agricultural herbicides in forestry is an adaption of a well established agricultural technology. Von Althen (1977) was the first in Ontario to investigate the use of simazine with selected poplar clones. He noted that simazine could be used at rates up to 4.5 kg/ha with *Populus* x *euramericana* (Dode) Guinier cv. 'I-45/51'. *Poplulus deltoides* x *Jackii* cv. 'DJAC 14' and *Poplulus alba* x *davidiana* cv. 'AK 30' were more susceptible to the chemical. AFOCEL (Association Foret-Cellulose) of France has also screened a range of *Populus* hybrids and clones (Bonduelle, 1980). The AFOCEL results differ markedly from those of Von Althen. In France, simazine was found to be useful only at low dosage rates; balsam type poplars were found to be more resistant to simazine; differences between clones were not great. The comparison of these two sets of results illustrates the highly specific nature of the herbicide-environment interaction.

The present research and development work attempts to adapt agricultural herbicide technology to the cultivation of a total of eight clones of the genus *Populus* on three contrasting old field sites in eastern Ontario. This process involves the transformation of an old field to a cultivated field and finally to a forest site. The productivity of the land will be shifted from the production of "weeds" to the production of "crops". High density, 35K plantings (35,000 stems/ha) established with 25 cm long unrooted cuttings were used to evaluate the treatments. The aim is to maximize biomass production.

Randomized block experiments were superimposed over the plantings; each experiment consisting of a range of rates for each of a number of carefully selected herbicides. The treatments were evaluated primarily for their effect on poplar biomass production. The trials reported on here were selected from a series established in eastern Ontario from 1975 to 1981. Each trial is intended to solve a particular problem related to site, target vegetation, clone or planting stock. Thirty herbicide treatments presented in this study were identified as being capable of producing biomass equivalent to three to four times that of the control.

Methods

Procedures

During the summer prior to the establishment of the experiment, each site was totally cultivated. This involved deep plowing to a depth of 25 cm, multiple discings to a depth of 20 cm and the incorporation of EPTC at the rate of 8.96 kg/ha. (Table 6-1 lists chemical, common names and tradenames for the herbicides discussed in this chapter.) EPTC is a non- selective, total kill site preparation herbicide with a half-life of only one week. No EPTC residue should have been present on the site at planting time. With the completion of site preparation by mid- to late August, all competition should have been removed from the trial area. Nothing was done to protect the prepared site from reinvasion by competing vegetation.

In April of the following spring, cuttings 25 cm long and 1 cm to 2 cm in diameter were planted vertically into the ground until the top was flush with the surface. The density was 35,000 plants per hectare, (i.e., 0.30 m within the row and 1.0 m between the rows). Plots were superimposed over the planted area. Plot size was 3 m by 6 m.

The amount of chemical required for each plot was predetermined, measured in the laboratory and transported to the site in 1 L glass jars. The same amount of water was added to each jar at the site. An agricultural plot sprayer was used to apply the chemical treatments to each plot. Nitrogen was used to pressurize the sprayer.

The Experimental Design

At each site a randomized block experiment with four replications was used. Not all herbicides were applied to each site; limited experimental area existed in each case. The decision as to what herbicides would be applied to a particular site was based on the soil characteristics, the target vegetation and the results of agricultural experience.

Each herbicide was applied at a range of concentrations spanning the recommended agricultural rates. Generally the rates started at levels extremely low and sub-toxic to both the target vegetation and the poplar, and were expanded, in a geometric fashion, to rates that, it was hoped, would be toxic not only to the target vegetation but also to the poplar. The primary consideration in these experiments was the effect of the herbicide on poplar biomass production. The effect of the herbicide on the target vegetation confirmed the results given in the agricultural literature.

The Soils

Soil descriptions for each of the three test sites are given in Table 6-2. Grenville 7 is located at the flood plain of Kemptville Creek. The site may be

Table 6-1

Herbicides referred to in this chapter and their formulations classified by chemical group

Chemical Group	Common Name	Tradename	Formulations							
			EF	EM	Fl	GR	SG	Sn	Su	WP
1. Acetamide	Metolachlor	Dual	X							
2. Amides	Alachlor	Lasso	X			X				
	Diphenamide	Enide		X		X				X
	Napropamide	Devrinole	X			X				X
3. Glycine	Glyphosate	Roundup						X		
4. Thiocarbamates	Butylate	Sutan	X			X				
	EPTC	Eptam	X			X				
5. Triazines	Atrazine	Aatrex			X	X	X	X	X	X
	Cyanazine	Bladex				X		X	X	X
	Metribuzin	Lexone/Sencor					X	X		X
	Simazine	Princep				X		X	X	X
6. Triazole	Amitrole	Cytrol						X		
	Amizine	(Amitrole + Simazine)		X						X
7. Uracils	Terbacil	Sinbar								X
8. Ureas	Chlorbromuron	Maloran								X
	Diuron	Karmex								X
	Linuron	Lorox								X
	Metobromuron	Patoran								X

Where:

EC	Emulsifiable Concentrate
EM	Emulsion
Fl	Flowable
GR	Granular
SG	Soluable Granules
Sn	Solution
Su	Suspension
WP	Wettable Powder

AN EMULSIFIABLE CONCENTRATE is produced by dissolving the active ingredient and an emulsifying agent in an organic solvent. This concentrate is often used to form an emulsion in water.

AN EMULSION is a dispersion of the fine droplets of one liquid into another without the droplets dissolving. The general form is as an oily substance carried in water.

A GRANULAR formulation contains dissolved chemical sprayed into or mixed with a solid carrier such as clay. A range of sizes of clays can be used. This form is generally used for soil treatments as the granules roll off of the plants to minimize crop residues.

SOLUBLE GRANULES are available as a powder that can be dissolved directly in water without a carrier. There is an advantage in ease of handling and mixing when only water is used.

A SOLUTION is a homogeneous mixture in a liquid form. Handling and dilution is easier than with other formulations where there is concern for settling and/or separation.

SUSPENSIONS involve particles of a solid or liquid dispersed in a carrier but not dissolved in it. Temperature changes or lack of agitation may cause settling of the active ingredient.

A WETTABLE POWDER is a powder formulation with enough wetting agent to suspend the powder for spraying. The amount and type of wetting agent may be important as conditions such as hardness of water can affect wettability. Nozzle wear on equipment requires frequent calibration.

Adopted from the Weed Science Society of America Herbicide Handbook, 1979.

Note: The use of tradenames does not imply endorsement by the Ontario Ministry of Natural Resources, but are included only for the information of the reader.

Table 6-2

Comparison of sites and soil factors affecting herbicide use

	Grenville 7			Grenville 34				Domtar II					
								(Soil Type G)			(Soil Type C)		
Texture by horizon (OMNR 1979)	A SANDY LOAM	B LOAMY SAND	C CLAY	A LOAM	B F.SANDY LOAM	B* LOAMY SAND	C SILT LOAM	A LOAM	B CLAY LOAM	C F.SANDY LOAM	Ap SANDY LOAM	B MED. SAND	C MED. SAND
Depth by horizon	0-19 cm	19-50 cm	50-100 cm	0-15 cm	15-30 cm	30-52 cm	52-100 cm	0-20 cm	20-51 cm	51-100 cm	0-25 cm	25-60 cm	60-100 cm
Drainage	Imperfectly drained (prominent mottles present in B horizons)			Imperfectly drained (prominent mottles present in all horizons)				Imperfectly to poorly drained (matrix dull; faint mottles only)			Imperfectly to poorly drained (matrix very dull; no prominent mottles)		
Per cent organic matter based on colour (Armson, 1977)	1.8	0.6	0.6	1.8	0.6	1.0	1.0	1.0	0.4	0.3	1.0	6.6	0.3
pH	6.4	7.2	7.5	7.2	7.1	7.5	7.7	6.1	6.2	7.1	7.0	6.6	7.4
	(no free carbonates present)			(free carbonates present in B and C)				(free carbonates present in B and C)			(free carbonates present in C horizon)		

flooded from time to time; within the duration of this experiment this did not occur. All sites were "idle" prior to the estabishment of the experiment and not in any crop production. The predominant vegetation on the sites was the rhizomous grass Agrigropyrons repens (L.) Beuv. This troublesome perennial spreads by both seed and underground stems. Agropyrons was eliminated by total cultivation prior to the establishment of the experiment. This was done in order to provide a fair test of the ability of the series of treatments to prevent the re-emergence of Agropyrons and annual weed species without being toxic to poplar.

The Clones

The clones chosen for these experiments are listed in Table 6-3.

Materials

All the herbicides screened all have agricultural registrations. Their environmental effects and their toxicity have been examined. The materials and their formulations are listed in Table 6-1. The 18 herbicides listed have been divided into eight chemical groups. Chemicals within the same group tend to have similar characteristics and similar modes of action. The formulation and the method of application of the chemical can greatly effect the efficacy of the treatment.

Table 6-3

The clones used in the experiments

Ontario Code	Hybrid	Clonal No. or Cultivar Name	Country of Origin
	Aigeiros Varieties		
DN 1	*P.* × *euramericana*	'Allenstein'	West Germany
DN 2	*P.* × *euramericana*	'Baden 431'	West Germany
DN 16	*P.* × *euramericana*	'Regenere Batard d'Hauterive'	France
DN 22	*P.* × *euramericana*	'I-262'	Italy
DN 74	*P. deltoides* × *nigra*		Ontario, Canada
I-45/51	*P.* × *euramericana*	'I-45/51'	Italy
	Tacamahaca Varieties		
JAC 4	*P.* × *jackii*		Ontario, Canada
DTAC 1	*P. angulata* × *berolinensis*		Wisconsin, USA

Data Collection

The total height of every stem in each trial was measured at the end of the growing season in years one, two and three. Data was collected so that the growth of a particular stem could be followed from year to year. Mortality was indicated by the absence of a number.

Based on the height measurement, three parameters were developed: survival per plot average height per plot and cumulative height per plot.

Survival is affected by treatment toxicity and by competition. Treatment evaluation cannot be based on survival alone. Average height is a treatment charactertistic but it is biased in that it does not give any account of mortality as a result of either toxicity or competition. Cumulative height per plot incorporates average height and survival into one parameter. It can be considered an index of biomass production.

Results

The Span of the Experiment

For each treatment on each site, and with each clone, the following treatment ratio was calculated:

$$\frac{\text{Mean Cumulative Height per Plot for each Treatment}}{\text{Mean Cumulative Height per Plot for the Control}}$$

The control used in each case was specific to the site and clone involved. All control values as treatment ratios were thus assigned the value of 1.00.

The efficacy of each treatment was evaluated at the mid-point of the growing season in year one. This was a estimation of the weed cover in every plot (i.e., zero implies zero efficacy and thus complete weed cover over the plot; 10 implies 100 per cent efficacy and thus no weed cover over the plot).

At the mid-point of the growing season in year one, the presence or absence of particular weed species was noted in every plot. This provided the weed spectrum data.

Height measurements were used to evaluate the treatments. The efficacy and weed spectrum data were used to corroborate the findings from agriculture.

The treatment ratios are given in Table 6-4. This table provides the span of the experiment. While this approach is non-statistical, it is effective in condensing a very large data set to manageable size.

Examination of the ratios in Table 6-4 provides the following insights into poplar biomass response to herbicide treatment. Comparable ratios for years two and three are found in Appendix 3 and Appendix 4.

CONTROL: No treatment.

AMIZINE: This chemical is a mixture of simazine and amitrole. It has both pre-emergence and post-emergence activity. A response of 409 per cent of the control is achieved at 2.24 kg/ha active ingredient. This response has declined to 176 per cent at 8.96 kg/ha. At this high rate, survival has been reduced but the characteristic average height growth has been maintained. The ratios for years two and three indicate a shift of the maximum to 3.92 kg/ha as herbicide degradation proceeds.

ATRAZINE plus ALACHLOR: Atrazine is an s-triazine with pre- and post-emergence activity. It is more soluble than simazine. Alachlor is an amide with pre-emergence activity. With atrazine fixed at 1.12 kg/ha and alachlor varying from 0.565 kg/ha to 4.48 kg/ha, a toxicity response was not obtained in year one. If this was the mixture of choice, the lowest alachlor rate would probably be adequate. Of the three clones tested, the greatest response was with 'DN 1' in year one and with 'DN 22' in years two and three. Atrazine, as a result of its mobility in the soil, may create, over time, mortality in some clones.

Table 6-4

Results in year one with all treatment results expressed as a ratio of the control

The ratio is $\frac{\text{Mean cumulative height per plot per treatment}}{\text{Mean cumulative height per plot for control}}$

Treatment Chemical Rate (kg/ha (lb/ac))	Grenville 7d(3) (1977)			Domtar 11('78)	Grenville 34A (1978)	Grenville 34B (1978)		
	DN22	DN1	JAC4	1-45/51	DN2	DN74	DTAC1	DN16
Control	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Amizine .56 (.5)					3.29			
1.12 (1.0)					3.90			
2.24 (2.0)					4.09			
3.92 (3.5)					3.85			
"					2.98			
"					2.46			
"					3.04			
"					2.88			
"					3.23			
"					2.85			
8.96 (8.0)					1.76			
Atrazine 1.12 (1.0) plus Lasso .56(.5)	1.75	2.04	1.41					
1.12(1.0)	1.58	2.27	1.61					
2.24(2.0)	1.49	2.15	1.86					
4.48(4.0)	1.72	2.30	1.62					
Cyanazine .56 (.5)	1.25	1.88	1.45					
1.12 (1.0)	1.54	1.84	1.55					
2.24 (2.0)	1.43	2.16	1.63					
4.48 (4.0)	1.27	2.09	1.58					
8.96 (8.0)	1.42	2.15	1.64					
Cyanazine 4.48 (4.0) and Atrazine .56 (.5)				1.58				
1.12 (1.0)				2.41				
2.24 (2.0)				2.23				
4.48 (4.0)				.64				
8.96 (8.0)				.58				

Table 6-4 continued

Treatment Chemical Rate (kg/ha (lb/ac))	Grenville 7d(3) (1977)			Domtar 11('78)	Grenville 34A (1978)	Grenville 34B (1978)		
	DN22	DN1	JAC4	1-45/51	DN2	DN74	DTAC1	DN16
Cyanazine 4.48 (4.0) & Alachlor .56 (.5)				2.15				
1.12 (1.0)				2.15				
2.24 (2.0)				2.45				
4.48 (4.0)				1.74				
8.96 (8.0)				2.01				
Cyanazine 4.48 (4.0) & Terbacil .28 (.25)				2.12				
.56 (. 5)				2.28				
1.12 (1.0)				1.99				
2.24 (2.0)				2.61				
4.48 (4.0)				1.64				
C.G.A. 18762 .28 (.25)						2.08	1.84	1.11
4.48 (4.0)						3.01	2.86	1.80
Diuron .56 (.5)					4.13			
1.12 (1.0)					3.71			
2.24 (2.0)					2.55			
"					3.34			
"					3.09			
"					3.32			
"					2.60			
"					2.40			
"					2.87			
4.48 (4.0)					2.48			
8.96 (8.0)					.54			

Treatment Chemical Rate (kg/ha (lb/ac))	Grenville 7d(3) (1977)			Domtar 11('78)	Grenville 34A (1978)	Grenville 34B (1978)		
	DN22	DN1	JAC4	1-45/51	DN2	DN74	DTAC1	DN16
Diuron 1.68 (1.5) & Napropamide 0.56 (0.5)				2.43				
1.12 (1.0)				1.91				
2.24 (2.0)				2.04				
4.48 (4.0)				2.09				
8.96 (8.0)				2.45				
Diuron 1.68 (1.5) & Diphenamid 1.12 (1.0)	0.79	2.18	1.27					
2.24 (2.0)	1.77	1.86	1.27					
4.48 (4.0)	1.89	2.06	1.81					
8.96 (8.0)	0.97	2.03	1.56					
Diuron 1.12 (1.0) & Simazine 0.56 (0.5)						3.25	2.94	1.58
1.12 (1.0)						2.70	2.89	1.56
2.24 (2.0)						2.02	2.10	1.62
4.48 (4.0)						1.59	1.86	1.12
8.96 (8.0)						0.63	0.94	1.03
Metolachlor 0.56 (0.5)						1.11	0.97	0.51
1.12 (1.0)						1.09	1.25	0.80
4.48 (4.0)						1.45	1.12	0.56
8.96 (8.0)						1.74	1.30	0.90
						1.40	1.68	0.60
EPTC 8.96 (8.0) & Metribuzin 0.28 (0.2)						2.34	2.17	1.03
1.12 (1.0)						2.60	2.58	1.46
4.48 (4.0)						1.45	1.90	0.98

Table 6-4 continued

Treatment Chemical Rate (kg/ha (lb/ac))	Grenville 7d(3) (1977)			Domtar 11('78)	Grenville 34A (1978)	Grenville 34B (1978)		
	DN22	DN1	JAC4	1-45/51	DN2	DN74	DTAC1	DN16
Alachlor .28 (.25)						1.60	1.57	.62
1.12 (1.00)						1.83	1.83	.96
4.48 (4.00)						1.16	1.12	.75
Alachlor 2.24 (2.0) and Atrazine .28 (.25)					3.42			
.56 (.50)					3.73			
1.12 (1.00)					2.88			
2.24 (2.00)					2.34			
Metribuzin .28 (.25)	.94	1.76	1.33			1.56	1.97	1.25
.56 (.5)	.90	1.30	1.18			2.50	2.44	1.47
1.12 (1.0)	.91	1.70	1.53			2.23	2.52	1.27
2.24 (2.0)	1.47	1.58	1.23			2.33	2.83	1.29
3.92 (3.5)	.55	1.11	.28			1.95	2.29	1.18
8.96 (8.0)	.49	.42	.09			1.35	1.69	.48
Metribuzin .56 (.5) and Diphenamid 1.12 (1.0)	1.65	1.82	1.27					
2.24 (2.0)	1.45	2.01	1.47					
4.48 (4.0)	1.50	1.81	1.31					
8.96 (8.0)	1.02	2.34	1.31					
Metribuzin .28 (. 25)						2.45	2.44	1.51
.56 (.5)	1.33	1.35	1.13					
1.12 (1.0)	1.27	1.56	1.17			2.87	2.76	1.58
2.24 (2.0)	1.47	2.01	1.30					
4.48 (4.0)	.61	1.87	.98			1.21	1.36	.82
8.96 (8.0)	.04	.67	.08					

Treatment Chemical Rate (kg/ha (lb/ac))		Grenville 7d(3) (1977)			Domtar 11('78)	Grenville 34A (1978)	Grenville 34B (1978)		
		DN22	DN1	JAC4	1-45/51	DN2	DN74	DTAC1	DN16
Linuron 2.24 (2.0) And Amitrole	.56 (.5)				2.41				
	1.12 (1.0)				2.38				
	2.24 (2.0)				1.67				
	4.48 (4.0)				2.25				
	8.96 (8.0)				1.72				
Linuron 2.24 (2.0) and Diphenamid	.56 (.5)				2.45				
	1.12 (1.0)				2.44				
	2.24 (2.0)				2.29				
	4.48 (4.0)				1.98				
	8.96 (8.0)				1.83				
Linuron 1.12 (1.0) & Alachlor	.56 (.5)	1.09	2.24	1.87					
	1.12 (1.0)	1.13	1.68	1.26					
	2.24 (2.0)	1.09	1.90	1.50					
	4.48 (4.0)	1.50	1.91	1.27					
Linuron 2.24 (2.0) and Alachlor	.56 (.5)						2.16	2.25	1.56
	1.12 (1.0)						2.01	2.07	1.31
	2.24 (2.0)						2.91	2.87	1.72
	4.48 (4.0)						2.69	2.43	1.48
	8.96 (8.0)						2.83	2.63	1.39
Chlorbromuron	.56 (.5)						2.76	2.51	1.53
	1.12 (1.0)						3.03	2.50	1.53
	2.24 (2.0)						2.50	2.41	1.62
	4.48 (4.0)						2.11	2.01	1.02
	8.96						.94	.99	.55
	17.92 (16.0)								

Table 6-4 continued

Treatment Chemical Rate (kg/ha (lb/ac))	Grenville 7d(3) (1977)			Domtar 11('78)	Grenville 34A (1978)	Grenville 34B (1978)		
	DN22	DN1	JAC4	1-45/51	DN2	DN74	DTAC1	DN16
Chlorbromuron 2.24 (2.0) & Metolachlor .56 (.5)						2.24	2.15	1.30
1.12 (1.0)						3.09	2.76	1.92
2.24 (2.0)						2.28	2.46	1.63
4.48 (4.0)						2.91	2.67	1.26
8.96 (8.0)						2.83	2.57	1.39
Chlorbromuron 2.24 (2.0) Alachlor .56 (.50)				2.87				
1.12 (1.00)				2.02				
2.24 (2.00)				2.47				
4.48 (4.00)				2.35				
8.96 (8.00)				1.87				
Mechanical				1.37	1.61	1.19	1.09	.42
"					1.06			
"					1.03			
"					1.64			
"					1.09			
					1.41			
Metobromuron .56 (.5)	1.81	1.98	1.36					
1.12 (1.0)	1.19	1.95	1.67					
2.24 (2.0)	1.41	2.10	1.40					
4.48 (4.0)	1.55	2.05	.98					
8.96 (8.0)	.94	1.91	.58					
17.92 (16.0)	.10	.80	0					
Simazine .56 (.5)	1.38	1.99	1.75		2.65			
1.12 (1.0)					3.66			
2.24 (2.0)	1.77	1.97	1.85		3.66			
4.48 (4.0)	1.67	2.49	1.73		3.23			
8.96					1.28			

Treatment Chemical Rate (kg/ha (lb/ac))	Grenville 7d(3) (1977)			Domtar 11('78)	Grenville 34A (1978)	Grenville 34B (1978)		
	DN22	DN1	JAC4	1-45/51	DN2	DN74	DTAC1	DN16
Simazine 1.12 (1.0) & Napropamide .56 (.5)					3.68			
1.12 (1.0)					4.13			
2.24 (2.0)					4.41			
4.48 (4.0)					3.91			
"					3.52			
"					2.43			
"					2.57			
"					3.12			
"					2.79			
8.96 (8.0)					3.90			
					4.02			
Simazine 1.12 (1.0) and Diuron 0.00						2.60	2.65	1.60
" .28 (.25)						2.92	2.71	1.63
" .56 (.5)						2.49	2.54	1.58
" 1.12 (1.0)						2.88	2.97	1.82
" 4.48 (4.0)						2.55	2.48	1.53
Simazine 2.24 (2.0) & Metolachlor .56 (.5)				2.79				
1.12 (1.0)				2.19				
2.24 (2.0)				2.56				
4.48 (4.0)				2.05				
8.96 (8.0)				2.34				
Simazine 1.12 (1.0) & Diphenamid .56 (.5)					4.13			
1.12 (1.0)					4.72			
2.24 (2.0)					3.93			
4.48 (4.0)					3.34			
8.96 (8.0)					3.69			

Table 6-4 continued

Treatment Chemical Rate (kg/ha (lb/ac))		Grenville 7d(3) (1977)			Domtar 11('78)	Grenville 34A (1978)		Grenville 34B (1978)	
		DN22	DN1	JAC4	1-45/51	DN2	DN74	DTAC1	DN16
Simazine 1.12 (1.0) & Metribuzin	.28 (.25)	1.53	2.19	1.60					
	1.12 (1.0)	1.39	2.20	.99					
	2.24 (2.0)	1.59	2.04	1.39					
	4.48 (4.0)	1.23	1.62	.99					
Simazine 2.24 (2.0) & Metribuzin	.56 (.5)				2.33				
	1.12 (1.0)				1.88				
	2.24 (2.0)				1.37				
	4.48 (4.0)				.83				
	8.96 (8.0)				.14				
Simazine 1.12 (1.0) & Linuron	.56 (.5)	1.45	2.39	1.58					
	1.12 (1.0)	1.07	1.90	1.13					
	2.24 (2.0)	1.99	1.99	1.44					
	4.48 (4.0)	.83	1.92	.52					
Simazine 3.36 & Glyphosate	1.12(1.0)				2.30				
	2.24(2.0)				2.25				
Simazine 1.12 (1.0) & Terbacil	.28 (.25)	1.58	2.73	1.80					
	.56 (.5)	1.77	1.95	1.75					
	1.12 (1.0)	1.34	2.04	1.55					
	2.24 (2.0)	1.51	2.38	1.70					
	4.48 (4.0)	1.62	2.68	1.96					
Terbacil	.28 (.25)						2.35	2.44	1.24
	.56 (.5)				2.41		2.59	2.97	1.77
	1.12 (1.0)				2.23		2.62	2.26	1.65
	2.24 (2.0)				.64		3.36	2.86	1.77
	4.48 (4.0)				.58		3.01	3.01	1.88

Treatment Chemical Rate (kg/ha (lb/ac))		Grenville 7d(3) (1977)			Domtar 11('78)	Grenville 34A (1978)	Grenville 34B (1978)		
		DN22	DN1	JAC4	1-45/51	DN2	DN74	DTAC1	DN16
Terbacil	.28 (.25)						2.35	1.44	1.24
	.56 (.50)						2.59	2.97	1.77
	1.12 (1.00)						2.62	2.26	1.65
	2.24 (2.00)						3.36	2.86	1.77
	4.48 (4.00)						3.01	3.01	1.88
Butylate 8.96 (8.00) & Diphenamid	.56 (.5)				1.23				
	1.12 (1.0)				1.31				
	2.24 (2.0)				.37				
	4.48 (4.0)				2.04				
	8.96 (8.0)				1.54				

CYANAZINE: This is an s-triazine with a half-life of 14 days. It is often the chemical of choice when triazine residues are a problem. There would not appear to be a toxicity problem even at 8.96 kg/ha in year one. The ratios are consistent in years two and three. A significant difference in clonal response is not apparent.

CYANAZINE plus ATRAZINE: In this combination, cyanazine is held constant at 4.48 kg/ha while atrazine varies from 0.56 kg/ha to 8.96 kg/ha. A definite toxicity response is apparent with 4.48 kg/ha of atrazine (plus the cyanazine at 4.48 kg/ha) producing only 64 per cent of the biomass of the control. A maximum response is achieved in year one with 1.12 kg/ha of atrazine (plus 4.48 kg/ha cyanazine). This maximum is 241 per cent of the control. The pattern remains consistent in years two and three.

CYANAZINE plus ALACHLOR: Cyanazine is held constant while alachlor varies from 0.56 kg/ha to 8.96 kg/ha. All treatments in all years are in the order of 200 per cent of the control.

CYANAZINE plus TERBACIL: Terbacil is a uracil with a half-life of five to six months. In this sequence, cyanazine is held constant at 4.48 kg/ha while terbacil varies from 0.25 kg/ha to 4.48 kg/ha. No significant toxic effects are evident in years one, two or three.

C.G.A. 18762: This numbered compound was developed by Ciba-Giegy. Registration has not proceeded with the material and it has been removed from our testing program. Significant toxic effects are evident with this material at 4.48 kg/ha in years two and three.

DIURON: This compound is a substituted urea which persists for up to one season. For each of the three years the maximum response of 344 per cent to 413 per cent occurs at the lowest rate (0.5 kg/ha). Toxicity is well defined with response declining as dosage increases.

DIURON and NAPROPAMIDE: Napropamide is an amide compound with a half-life of eight to 12 weeks. In this combination diuron was held constant at 1.68 kg/ha while napropamide varied from 0.5 kg/ha to 8.96 kg/ha. The treatment response is similar in each of the three years. No dominant response pattern is evident.

DIURON AND DIPHENAMID: Diphenamid is another amide with persistence at herbicidal levels for three to six months. Diruon was held constant at 1.68 kg/ha in this combination while diphenamid varied from 1.12 kg/ha to 8.96 kg/ha. The response is similar in all three years. No major pattern emerges.

DIURON AND SIMAZINE: This potent combination of a substituted urea and an s-triazine showed a maximum response in year one at the lowest dosage (diuron at 1.12 kg/ha and simazine at 0.56 kg/ha). As the simazine rate increased, the response declined. With diuron at 1.12 kg/ha and simazine at 8.96 kg/ha, the response was only 63 per cent to 103 per cent of the level of the control. Universal toxicity is evident in years two and three for all clones tested.

METOLACHLOR: This acetamide has pre-emergence activity and a half-life of 15 to 25 days. In year one, there is not a major positive response. In years two and three, universal toxicity occurs. Initially, clones 'DN 74' and 'DTAC 1' show greater resistance to the herbicide than does clone 'DN 16'.

EPTC and METRIBUZIN: EPTC is a thiocarbamate with a half-life of one week. It is a non-selective site preparation chemical which must be pre-plant incorporated. Metribuzin, classified as an s-triazine, has a half-life of 14 to 18 days. In year one, the maximum response occurs at 1.12 kg/ha. In years two and three, major toxicity problems are evident.

ALACHLOR: This amide has a persistence of six to 10 weeks. In year one 'DN 16' is more susceptible to the compound than either 'DN 74' or 'DTAC 1'. The response of these latter clones is very similar. In years two and three the response ratios are not significantly different from those of the control.

ALACHLOR and ATRAZINE: Alachlor is held constant at 2.24 kg/ha while atrazine varies from 0.25 kg/ha to 2.24 kg/ha. In year one the maximum response occurs with atrazine at 0.56 kg/ha. This response pattern remains consistent in years two and three.

CHLORBROMURON: This substituted urea has a half-life of 45 days. In year one a strong positive response is obtained at 1.12 kg/ha with clones 'DN 74' (303 per cent) and 'DTAC 1' (250 per cent). Neutral and negative results are evident in years two and three.

CHLORBROMURON and METOLACHLOR: With chlorbromuron at 2.24 kg/ha and metolachlor varying from 0.56 kg/ha to 8.96 kg/ha, a generally positive response is obtained in year one. The response is stronger with 'DN 74' and 'DTAC 1' than with 'DN 16'. Neutral and negative results are obtained in years two and three.

CHLORBROMURON and ALACHLOR: With chlorbromuron set at 2.24 kg/ha and alachlor varying from 0.56 kg/ha to 8.96 kg/ha a strong positive response of more or less 200 per cent of the control is consistently produced for years one, two and three.

MECHANICAL: This treatment consisted of hand weeding. For the most part these treatments are not significantly different from the control. This may be more a reflection of the diligence with which the work was carried out rather than a true effect of treatment.

METOBROMURON: This is a substituted urea with pre-emergence activity. In year one, negative effects are apparent at 8.96 kg/ha. Strong positive effects are evident at 0.56 kg/ha to 2.24 kg/ha. The pattern is maintained in years two and three.

SIMAZINE: This common s-triazine is the basis for pre-emergence control currently within the program. A positive and consistent response is observed for all years at rates between 0.56 kg/ha and 4.0 kg/ha. Simazine has a half-life of 12 months. The response is stronger on Grenville 34 than on Grenville 7.

SIMAZINE and NAPROPAMIDE: Since 1975, this combination has proven to be one of the best. In year one, a response of 441 per cent is obtained with simazine at 1.12 kg/ha and napropamide at 2.24 kg/ha. This strong positive response is maintained in years two and three. The possible synergistic effects of this combination are being investigated and will be reported elsewhere.

SIMAZINE and DIURON: Here simazine is held constant at 1.12 kg/ha while diuron is allowed to vary from 0.0 kg/ha to 4.48 kg/ha. Strong positive effects are present in year one while neutral to negative effects predominate in years two and three.

SIMAZINE and METOLACHLOR: Simazine in this treatment was held at 2.24 kg/ha while metolachlor was allowed to vary from 0.56 kg/ha to 8.96 kg/ha. In years one, two and three, responses of 200 per cent and more are consistently achieved.

SIMAZINE and DIPHENAMID: This combination is very similar to that of simazine and napropamide. A maximum response of 472 per cent is obtained in year one with simazine at 1.12 kg/ha and diphenamid at 1.12 kg/ha. This strong positive response is maintained in years two and three.

METRIBUZIN: While some positive effects are present in year one, symptoms of toxicity are evident in later years.

METRIBUZIN and DIPHENAMID: With metribuzin used at a low rate of 0.56 kg/ha, its damaging effects are not readily evident. In this case there does not appear to be a consistent response to diphenamid as the dosage increases.

LINURON: Phytotoxic concentrations of this substituted urea remain for four months. In year one, the response maximum consistently occurs at 2.24 kg/ha on Grenville 7 and at 1.12 kg/ha on Grenville 34. In year two on Grenville 7, the dosage at which a maximum response occurs varies widely. In year two at Grenville 34, a consistent, positive response no longer exists. This chemical can be expected to provide variable performance based on site conditions.

LINURON and AMITROLE: No major phytotoxic response can be detected.

LINURON and DIPHENAMID: No major phytotoxic response can be detected.

LINURON and ALACHLOR: With linuron at 1.12 kg/ha and alachlor varying from 0.56 kg/ha to 4.48 kg/ha on the Grenville 7 site no major negative effects are evident. With linuron at 2.24 kg/ha and alachlor varying from 0.56 kg/ha to 8.96 kg/ha on Grenville 34, positive effects are observed in year one and neutral to negative effects in years two and three.

SIMAZINE and METRIBUZIN: Initially, simazine was held at 1.12 kg/ha while metribuzin was allowed to vary from 0.28 kg/ha to 4.48 kg/ha. Clones 'DN 22' and 'DN 1' appear to be more resistant to these treatments than is 'JAC 4'. With simazine at 2.24 kg/ha and metribuzin allowed to vary from 0.56 kg/ha to 8.96 kg/ha, toxic effects become apparent with metribuzin used above 2.24 kg/ha. This latter treatment sequence was completed on Domtar 11 with one of the more herbicide-tolerant clones, 'I-45/51'.

SIMAZINE and LINURON: Here simazine is held constant at 1.12 kg/ha while linuron is allowed to vary from 0.56 kg/ha to 4.48 kg/ha. At the highest linuron rate the positive response breaks down.

SIMAZINE AND GLYPHOSATE: In this combination, the response is similar to what is expected with simazine alone. This combination has both site preparation and tending properties. There does not appear to be an antagonistic reaction between these two chemicals when mixed.

SIMAZINE and TERBACIL: With this combination, simazine was held at 1.12 kg/ha while terbacil was allowed to vary from 0.28 kg/ha to 4.48 kg/ha. Consistent positive responses were obtained for all clones in all years. The test site was Grenville 7.

TERBACIL: With terbacil alone on Grenville 34, a different pattern emerges from that reported above. A strong positive effect occurs in year one while in years two and three some neutral to negative results appear.

BUTYLATE and DIPHENAMID: Inconsistent results.

The Statistical Analysis

The cumulative height per plot data were subjected to analysis of variance (two-way classification) and Duncan's multiple comparison of means.

The resulting first rank chemical treatments are given in Table 6-5, by test site, clone and herbicide.

The ranking is presented only for year one data. As noted during the ratio examination, toxicity effects

Table 6-5

Chemical treatments found to be rank 1 on the basis of Duncan's multiple comparison of means test
Rates of application in kg active ingredient per hectare

			Treatment (kg/ha) (kg of herbicide active ingredient per hectare)					
Site	Clone	Amizine	Atrazine & Alachlor	Cyanazine	Cyanazine & Atrazine	Cyanazine & Alachlor	Cyanazine & Terbacil	CGA 18762
Grenville 7d(3) (1977)	DN22		1.12 & .56	1.12				
			1.12 &4.48	2.24				
			1.12 &1.12	8.96				
			1.12 &2.24	4.48				
Grenville 7d(3) (1977)	DN1		1.12 &4.48	2.24				
			1.12 &1.12	8.96				
			1.12 &2.24	4.48				
Grenville 7d(3) (1977)	JAC4		1.12 &2.24	8.96				
			1.12 &4.48	2.24				
			1.12 &1.12	4.48				
			1.12 & .56	1.12				
				.56				
Domtar II (1978)	1-45/51					4.48 &2.24	4.48 &2.24	
					4.48 & 1.12	4.48 & .56	4.48 & .56	
					4.48 & 2.24	4.48 &1.12		
						4.48 &8.96		
Grenville 32A (1978)	DN2	2.24	.56 &2.24					
		1.12	.28 &2.24					
		3.92						
		.56						
Grenville 32B (1978)	DN74							4.48
Grenville 32B (1978)	DTAC1							4.48
Grenville 32B (1978)	DN16							4.48

Table 6-5 continued

		Treatment (kg/ha)							
Site	Clone	Diuron	Diuron & Napropamide	Diuron & Diphenamid	Diuron & Simazine	Metolachlor	EPTC & Metribuzin	Metribuzin	Metribuzin & Diphenamid
Grenville 7d(3) (1977)	DN22			1.68 &4.48 1.68 &2.24				2.24 1.12	.56 & 1.12 .56 & 4.48 .56 & 2.24
Grenville 7d(3) (1977)	DN1			1.68 & 1.12					.56 & 8.96
Grenville 7d(3) (1977)	JAC4			1.68 & 4.48 1.68 & 8.96				1.12	.56 & 2.24
Domtar II (1978)	1-45/51		1.68 & 4.56 1.68 & 4.48 1.12 2.24 1.12 & 8.96						
Grenville 32A (1978)	DN2	.12 .24							
Grenville 32B (1978)	DN74				1.12 & .56 1.12 & 1.12		8.96 & 1.12		
Grenville 32B (1978)	DTAC1				1.12 & .56 1.12 & 1.12		8.96 & 1.12	2.24 1.12 .56 4.48	
Grenville 32B (1978)	DN16				1.12 & 2.24 1.12 & .56 1.12 & 1.12	8.96	8.96 & 1.12	.56	

		Treatment (kg/ha)							
Site	Clone	Linuron	Linuron & Amitrole	Linuron & Diphenamid	Linuron & Alachlor	Chlor-bromuron	Chlorbromuron & Metolachlor	Chlorbromuron & Alachlor	Simazine
Grenville		2.24			1.12 & 4.48				2.24
7d(3) (1977)	DN22	.56							4.48
									.56
					1.12 & .56				4.48
Grenville	DN1								
7d(3) (1977)									
Grenville					1.12 & .56				2.24
7d(3) (1977)	JAC4				1.12 & 2.24				.56
									4.48
			2.24 & 1.12	2.24 & .56				2.24 & .56	
			2.24 & .56	2.24 & 1.12				2.24 & 4.48	
Domter II	1-45/51		2.24 & 4.48	2.24 & 2.24				2.24 & 1.12	
(1978)				2.24 & 4.48				2.24 & 2.24	
									1.12
Grenville	DN2								4.48
32A (1978)									
		1.12			2.24 & 2.24	1.12	2.24 & 1.12		
Grenville	DN74				2.24 & 8.96	.56	2.24 & 4.48		
32B (1978)					2.24 & 4.48		2.24 & 8.96		
		1.12			2.24 & 2.24	1.12	2.24 & 1.12		
		.28			2.24 & 8.96	.56	2.24 & 4.48		
Grenville	DTAC1				2.24 & 4.48	2.24	2.24 & 8.96		
32B (1978)							2.24 & 2.24		
		.12							
		.28			2.24 & 4.48	2.24	2.24 & 1.12		
Grenville	DN16					.56	2.24 & 2.24		
32B (1978)						1.12			

Table 6-5 continued

		Treatment (kg/ha)							
Site	Clone	Simazine & Napropamide	Simazine & Diuron	Simazine & Metolachlor	Simazine & Diphenamid	Simazine & Metribuzin	Simazine & Linuron	Simazine & Glyphosate	Simazine & Terbacil
Grenville 7d(3) (1977)	DN22					1.12 & 2.24	1.12 & 2.24		1.12 & .56
						1.12 & 1.12	1.12 & .56		1.12 & 4.48
						1.12 & .28			1.12 & .28
									1.12 & 2.24
									1.12 & 1.12
Grenville 7d(3) (1977)	DN1					1.12 & 1.12	1.12 & .56		1.12 & 4.48
						1.12 & .28			1.12 & 2.24
									1.12 & .28
Grenville 7d(3) (1977)	JAC4					1.12 & .28	1.12 & .56		1.12 & 4.48
						1.12 & 2.24	1.12 & 2.24		1.12 & .28
									1.12 & .56
									1.12 & 2.24
									1.12 & 1.12
Domtar II (1978)	1-45/5			2.24 & .56		2.24 & .56		3.36 & 1.12	
				2.24 & 8.96		2.24 & 1.12		3.36 & 2.24	
				2.24 & 1.12					
				2.24 & 2.24					
Grenville 32A (1978)	DN2	1.12 & 2.24			1.12 & 1.12				
		1.12 & 1.12			1.12 & 2.24				
		1.12 & 8.96			1.12 & 8.96				
		1.12 & 4.48			1.12 & 4.48				
Grenville 32B (1978)	DN74		1.12 & .28						
			1.12 & 1.12						
			1.12 & 0.00						
			1.12 & 4.48						
Grenville 32B (1978)	DTAC1		1.12 & 1.12						
			1.12 & .28						
			1.12 & 0.00						
			1.12 & .56						
			1.12 & 4.48						
Grenville 32B (1978)	DN16		1.12 & 1.12						
			1.12 & .28						
			1.12 & 0.00						
			1.12 & .56						
			1.12 & 4.48						

may not occur until years two or three. Herbicide degradation leads to lower residues on the sites over time and, therefore, lower rankings for some treatments in years two and three. Generally, the lowest dosage of a herbicide that produces a rank one response is the safest and the most appropriate to use.

Dosage Response by Clone and Chemical

Figures 6-1 and 6-2 show the response to rates of application of three different herbicides to three different clones on Grenville 7.

In Figure 6-1, response curves for metribuzin are depicted for clone 'DN 1' and clone 'JAC 4'. The regression lines are significantly different at $P = 0.05$. It would appear that as the dosage increases, 'JAC 4' becomes much more sensitive to metribuzin than does 'DN 1'. 'DN 1' is a cottonwood type poplar while 'JAC 4' is a balsam type poplar.

In Figure 6-2, response curves for metobromuron and linuron are shown for clones 'DN 22' and 'JAC 4'. 'DN 22' is a cottonwood type poplar. For clone 'DN 22' a different response is obtained with metobromuron than with linuron. These response curves are significantly different at the five per cent level. A similar pattern exists for clone 'JAC 4'.

Specific clones can have different responses to the different chemicals used. A clone-chemical interaction exists. Balsam type poplars may be more sensitive to chemical treatment than are cottonwoods. This adds to the complexity involved in formulating prescriptions.

The final product from weed spectrum data is an assessment of the ability of a herbicide to control a particular weed species at recommended agricultural

Figure 6-1

Response of clones 'DN 1' and 'JAC 4' to varying rates of application of Metribuzin on Grenville 7d3

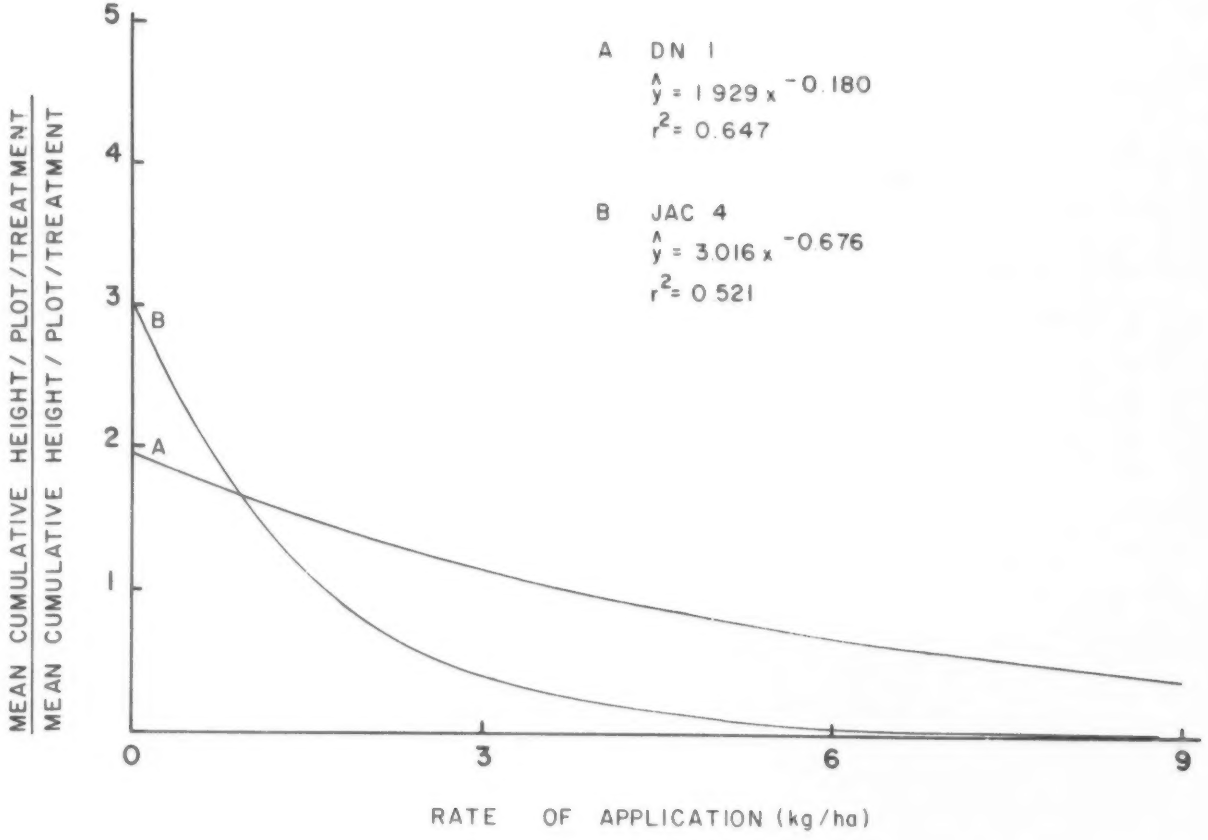


Figure 6-2

Response of clones 'DN 22' and 'JAC 4' to varying application rates of Metobromuron and Linuron on Grenville 7d3

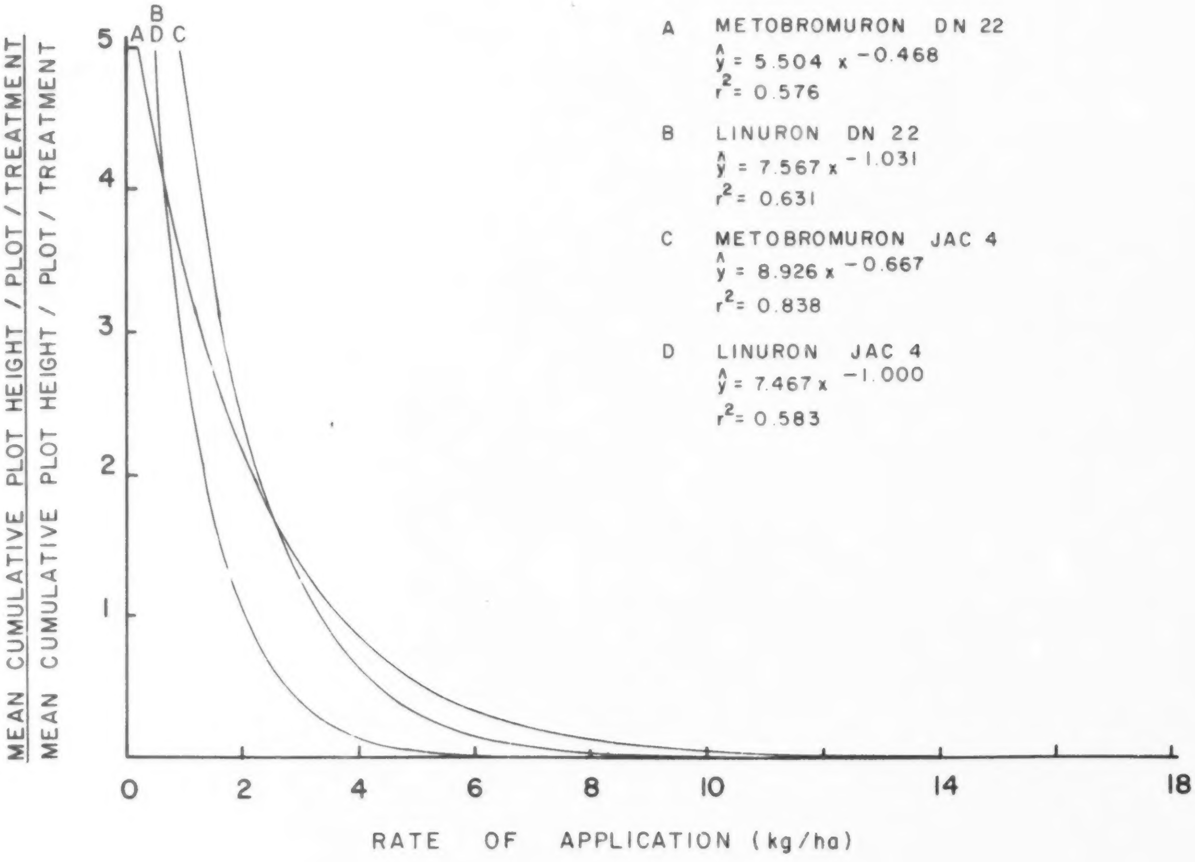


Table 6-6

Degree of weed control provided by chemical and/or chemical group

			Annual Broadleaves										Annual Grasses					Perennials						
Chemical Group	Treatment Name	Method	black bindweed - Polygonum convolvulus L.	corn spurrey - Spergula arvensis L.	lady's thumb - Polygonum persicaria L.	lamb's quarters - Chenopodium album L.	mustard - Brassica kaber (DC.) L. Wheeler	night shades - Solanum spp.	pig weeds - Amaranthus spp.	rag weeds - Ambrosia spp.	ragweed - triazine resistant variety	velvet leaf - Abutilon theophrasti Medic.	barnyard grass - Echinochloa crusgalli L. Beauv	crab grass - Digitaria spp.	fall panicum - Panicum dichotomiflorum Michx.	foxtail - Setaria spp.	old witch grass - Panicum capillare L.	bindweed, field - Convolvulus arvensis L.	horsetail, common - Equisetum arvense L.	milkweed - Asclepias syriaca L.	nutsedge - Cyperus esculentus L.	quack grass - Agropyron repens L. Beauv	thistle, Canada - Cirsium arvense L. Scop.	sow-thistle - Soncus arvensis L.
Acetamide	Metolachlor	Pre-emergence	P	P	P	P	P	G	P	P	P	P	E	E	G	E	E	P	P	P	P	P	P	*
		Preplant incorporated	P	P	P	P	P	G	P	P	P	P	E	E	G	E	E	P	P	P	G	P	P	P
Amides	Alachlor	Pre-emergence	P	P	P	P	P	G	P	P	P	P	E	E	G	E	E	P	P	P	P	P	P	P
		Preplant incorporated	P	*	F	F	P	G	P	P	*	P	E	E	E	E	E	P	P	P	F	P	P	P
	Diphenamide	Pre-emergence			#		#						#	#		#	#							
	Napropamide	Pre-emergence	#		#			#						#					#					

Chemical Group	Treatment Name	Method	Annual Broadleaves										Annual Grasses					Perennials						
			black bindweed - *Polygonum convolvulus* L.	corn spurrey - *Spergula arvensis* L.	lady's thumb - *Polygonum persicaria* L.	lamb's quarters - *Chenopodium album* L.	mustard - *Brassica kaber* (DC.) L. Wheeler	night shades - *Solanum* spp.	pig weeds - *Amaranthus* spp.	rag weeds - *Ambrosia* spp.	ragweed - triazine resistant variety	velvet leaf - *Abutilon theophrasti* Medic.	barnyard grass - *Echinochloa crusgalli* L. Beauv	crab grass - *Digitaria* spp.	fall panicum - *Panicum dichotomiflorum* Michx.	foxtail - *Setaria* spp.	old witch grass - *Panicum capillare* L.	bindweed, field - *Convolvulus arvensis* L.	horsetail, common - *Equisetum arvense* L.	milkweed - *Asclepias syriaca* L.	nutsedge - *Cyperus esculentus* L.	quack grass - *Agropyron repens* L. Beauv	thistle, Canada - *Cirsium arvense* L. Scop.	sow-thistle - *Soncus arvensis* L.
Glycine	Glyphosate	Pre-emergence	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	P	*	*	E	*	*
		Spot treatment	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	P	E	G	E	E	E
Thiocarbamates	Butylate	Preplant incorporated	P	G	P	F	P	G	F	F	P	P	E	E	G	E	E	P	P	P	G	P	P	*
	EPTC	Preplant incorporated	F	*	F	G	P	F	F	F	*	F	E	E	E	E	E	P	F	P	G	P	P	P
Triazines	Atrazine	Pre-emergence	E	E	E	E	E	E	E	E	P	F	G	P	P	G	G	P	P	P	P	F	P	*
		Post-emergence	E	E	E	E	E	E	E	E	P	F	G	P	P	F	G	P	P	P	F	F	P	F
		Split	E	E	E	E	E	E	E	E	P	F	E	F	F	E	E	F	F	P	G	E	G	G
	Cynazine	Pre-emergence	G	*	G	E	E	E	F	E	P	F	F	E	G	E	E	P	P	P	P	P	P	*
		Post-emergence	G	*	G	E	E	E	F	E	P	F	F	E	G	E	E	P	P	P	P	P	P	P
	Metribuzin	Pre-emergence			#	#	#		#	#	#	#	#	#	#	#	#							

Rating:

E - Excellent
G - Good
F - Fair
P - Poor

* - Indicates that the annual weeds will be controlled, if emerged, and that the perennials can be controlled, if treated at the optimum time, which is usually not the same time as for crabgrass

# - Indicates that the herbicide will control these weeds

Table 6-6 continued

Chemical Group	Treatment Name	Method	Annual Broadleaves										Annual Grasses					Perennials						
			black bindweed - *Polygonum convolvulus* L.	corn spurrey - *Spergula arvensis* L.	lady's thumb - *Polygonum persicaria* L.	lamb's quarters - *Chenopodium album* L.	mustard - *Brassica kaber* (DC.) L. Wheeler	night shades - *Solanum* spp.	pig weeds - *Amaranthus* spp.	rag weeds - *Ambrosia* spp.	ragweed - triazine resistant variety	velvet leaf - *Abutilon theophrasti* Medic.	barnyard grass - *Echinochloa crusgalli* L. Beauv	crab grass - *Digitaria* spp.	fall panicum - *Panicum dichotomiflorum* Michx.	foxtail - *Setaria* spp.	old witch grass - *Panicum capillare* L.	bindweed, field - *Convolvulus arvensis* L.	horsetail, common - *Equisetum arvense* L.	milkweed - *Asclepias syriaca* L.	nutsedge - *Cyperus esculentus* L.	quack grass - *Agropyron repens* L. Beauv	thistle, Canada - *Cirsium arvense* L. Scop.	sow-thistle - *Soncus arvensis* L.
Triazine	Simazine	Pre-emergence	#		#	#	#		#	#			#	#		#								
		Post-emergence	#		#	#				#			#	#		#								
Triazole	Amitrole	Pre-emergence	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	G	G	E
Uracil	Terbacil	Post-emergence			*		*		*	*			*	*		*					F	F		
Ureas	Chlorbromuron	Pre-emergence	E	*	E	E	E	G	E	G	*	F	E	E	E	E	E	P	P	P	P	P	P	P

			Annual Broadleaves										Annual Grasses					Perennials						
Chemical Group	Treatment Name	Method	black bindweed - *Polygonum convolvulus* L.	corn spurrey - *Spergula arvensis* L.	lady's thumb - *Polygonum persicaria* L.	lamb's quarters - *Chenopodium album* L.	mustard - *Brassica kaber* (DC.) L. Wheeler	night shades - *Solanum* spp.	pig weeds - *Amaranthus* spp.	rag weeds - *Ambrosia* spp.	ragweed - triazine resistant variety	velvet leaf - *Abutilon theophrasti* Medic.	barnyard grass - *Echinochloa crusgalli* L. Beauv	crab grass - *Digitaria* spp.	fall panicum - *Panicum dichotomiflorum* Michx.	foxtail - *Setaria* spp.	old witch grass - *Panicum capillare* L.	bindweed, field - *Convolvulus arvensis* L.	horsetail, common - *Equisetum arvense* L.	milkweed - *Asclepias syriaca* L.	nutsedge - *Cyperus esculentus* L.	quack grass - *Agropyron repens* L. Beauv	thistle, Canada - *Cirsium arvense* L. Scop.	sow-thistle - *Soncus arvensis* L.
Ureas	Diuron	Pre-emergence			#	#	#		#	#					#		#						#	
	Linuron	Pre-emergence	E	*	E	E	E	G	E	G	*	F	F	F	F	F	F	P	P	P	P	P	P	P
		Pre-emergence	E	E	E	E	E	E	E	E	E	E	E	F	E	G	E	F	E	F	G	F	G	F
	Metobromuron	Pre-emergence	E	*	E	E	E	G	E	G	*	F	F	F	F	F	F	P	P	P	P	P	P	P

Rating:

E - Excellent
G - Good
F - Fair
P - Poor

* - Indicates that the annual weeds will be controlled, if emerged, and that the perennials can be controlled, if treated at the optimum time, which is usually not the same time as for crabgrass

- Indicates that the herbicide will control these weeds

Source: Ontario Ministry of Agriculture and Food (OMAF), 1981 rates. A typical summary of this information is provided in Table 6-6. This table is a key piece of information in formulating herbicide prescriptions.

A basic principle underlies all weed spectrum data. A particular herbicide treatment cannot control all possible weed species. Once the dominant weed species has been removed from the site another will take its place. Continual shifts will occur in the weed population until the point at which weed control operations are no longer required and the crop is the dominant vegetative species on the site.

Release - Response Study

The plantation on Domtar 1 was established in 1975. Early weed control was mechanical and not entirely effective. In 1978 a trial was established to determine if the stand would respond to a chemical weed control treatment. A significant amount of Agropyrons repens was present at the time.

Fifty per cent of the stand was treated with a combination of glyphosate at 2.24 kg/ha and simazine at 2.24 kg/ha. The treated area consisted of strips located systematically throughout the entire plantation.

The results for clone 'DN 17' are presented in Table 6-7. No significant differences were found for average height in 1978, 1979 or 1980. After a one year delay, significant differences at $P = 0.05$ were found for average diameter. A major colour difference in the poplar foliage between the treated and untreated strips forewarned of this result during the summer of 1978.

Two major conclusions can be drawn from these results. First, that the stand was not free-to-grow at

Table 6-7

Results of release-response study at Domtar compartment I for clone 'DN 17'

	Average Height (m)			Average Diameter (cm)		
	1978	1979	1980	1978	1979	1980
Treated	4.2	6.2	7.6	3.6	6.2	7.5
Untreated	4.1	5.5	6.8	3.4	4.9	5.8
Difference between control and treatment	0.1	0.7	0.8	0.2	1.3*	1.7*

*Significant at P = .05

the time of treatment in 1978. Second, that the response to release did occur but it was delayed one year and is exhibited in diameter growth.

Discussion

Plantation Establishment

Once a soil survey has been completed and a decision made to plant hybrid poplar, the present condition and past use of the site must be considered. If the site is an old field it can be expected to have low levels of fertility and organic matter. The dominant form of vegetation in an old field will be rhizomous grasses. If the site is forested, it can be expected to have acceptable fertility and organic matter levels; rhizomous grasses are generally not present. Prior to the commencement of site preparation operations, all standing woody biomass must be removed from the site.

Two major chemical-mechanical site preparation options are currently available. The first involves the use of glyphosate. This is applied at a rate of 2.24 kg/ha to the target vegetation when it is actively growing and translocation through to the root system is taking place. Within 10 days of application, the target vegetation should be dead. The site is then plowed to a depth of 25 cm and disced several times to a depth of 20 cm.

The second chemical-mechanical method involves the use of the chemical EPTC. The site is first plowed to a depth of 25 cm and then disced to 20 cm. The incorporation of EPTC into the soil then follows at a rate of 8.96 kg/ha. The EPTC should kill all living plant matter within the soil, including root pieces of Agropyrons. The site preparation phase of operations is complete when all existing vegetation has been removed from the site.

The investment into site preparation must be protected. This is done by the application of a pre-emergence herbicide to the site, a procedure normally referred to as pre-plant tending. All operations to this stage take place during the summer prior to planting.

Planting in eastern Ontario begins in April. Cuttings 25 cm long and 1 cm to 2 cm in diameter are planted vertically into the ground, until the top is flush with the surface. Under conditions of high soil moisture and low temperatures, the cuttings develop vigorous root systems. Shoots develop from the rooted cuttings during May. Once planted, the site may require post-plant tending. Weed species resistant to the pre-emergence herbicide applied prior to planting can now be expected to invade the site. These invading plants will primarily consist of annual species. Once the target species have been identified, appropriate herbicide treatments must be selected to maintain 80% weed control. Post-plant weed control operations must be continued until the stand is considered free-to-grow. A flow chart of this operational sequence is given in Figure 6-3.

Through the effective use of herbicides, the potential of the site is shifted from the production of "weeds" to the production of a "crop". The site is transformed from an old field, to a cultivated field, to a forest stand.

The Chemicals and Their Use

Information on material residues and use characteristics is given in Table 6-8 by chemical group.

ACETAMIDES: Metolachlor is from this group. Negative to neutral results were obtained with this chemical in years two and three. It should only be used as a last resort.

AMIDES: Alachlor, diphenamid and napropamide are from this group. These may be referred to as the soft chemicals. They may not be completely effective for a whole season if used singly. In combination with simazine at a low dosage, a very consistent and positive response can be obtained.

GLYCINES: Glyphosate (Roundup) is a very effective, total kill, site preparation herbicide. It must be applied when the target vegetation is actively growing. This chemical has successfully been applied in mixture

Table 6-8

Herbicide residue and use characteristics, classified by chemical group

Chemical Group	Common Name	Tradename	Leaching Characteristics	Half-life of residue	Constraints to use
Acetamide	Metolachor	Dual	no significant leaching when organic matter < 2.0%	northern 30-50 days; southern 15-25 days.	not for muck, peat muck, or high organic content soil.
Amides	Alachlor	Lasso	absorbed by soil colloids.	persistent for 6-10 weeks; less in soils low in organic matter.	none
	Diphenamid	Enide	rapidly leached in sandy soils, slowly in loam or clay soils.	persistent at herbicidal levels for 3-6 months	retention in seed germination zone can be a problem in times of heavy rains
	Napropamide	Devrinol	1" in clay and silt 2" in loam; 8" in loamy sand; and 8" when water supplied	8-12 weeks	none
Glycine	Glyphosate	Roundup	very low leaching activity	soil residuals 10% within 1 growing season.	none
Thiol-carbamates	Butylate	Sutan	sandy soil: 1/3 the distance that 8" of water moves clay organic soil (1-3")		none
	EPTC	Eptam	in sandy soil 9-15" loam and clay 3-6" in 8" of water	1 week in moist loam	none

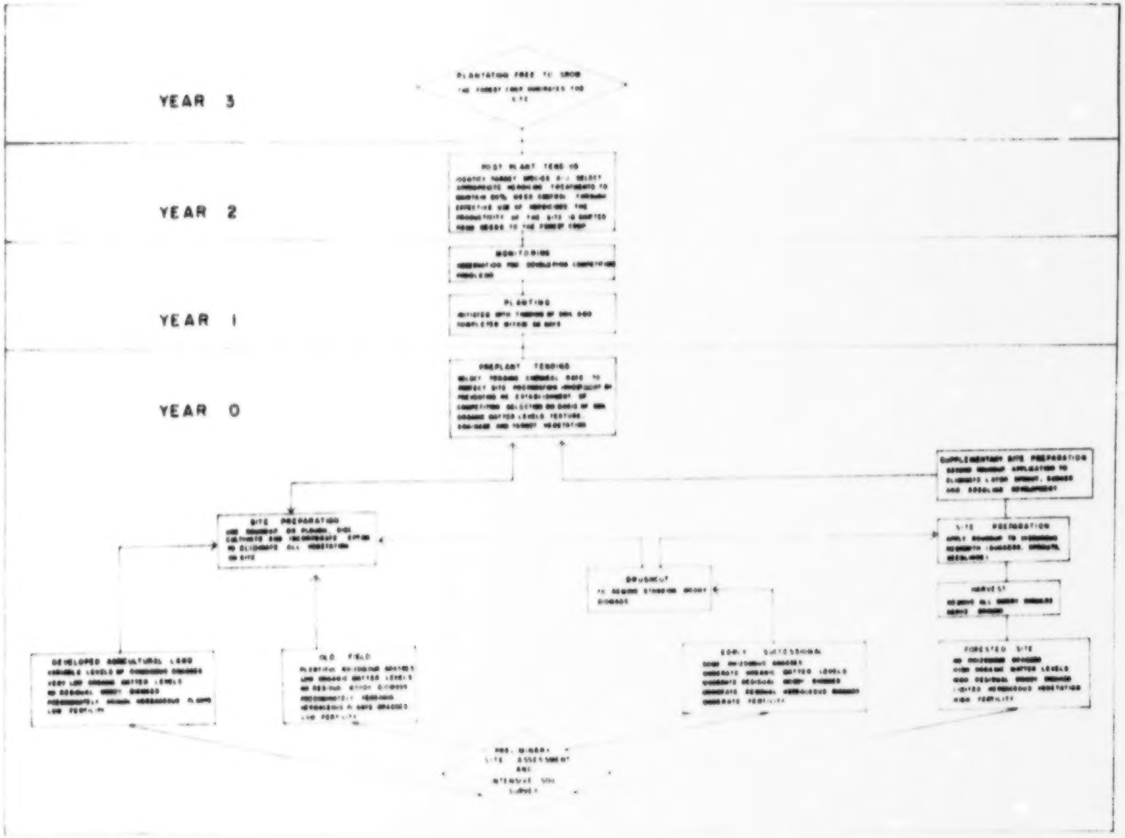
Chemical Group	Common Name	Tradename	Leaching Characteristics	Half-life of residue	Constraints to use
Triazines	Atrazine	Aatrex	not usually found below 1 foot.	residual carry-over of 12 months.	none
	Cyanazine	Bladex	4.5" in sandy loam if 2" of water supplied.	2 weeks under favourable conditions	not recommended for heavy soils such as brookstone clay or muck
	Metribuzin	Lexone/Sencor	high in sandy soils; low in heavy soils; little in highly organic soils.	14-18 days	not for muck or highly organic soil.
	Simazine	Princep	2" usually	12 months	none
Triazole	Amitrole	Cytrol		persistence is 2-4 weeks.	heavy doses leave soil barren for a period of time.
Uracil	Terbacil	Sinbar		5-6 months	not for sandy or highly mineral soils (less than 1% organic matter)or on eroded areas
Ureas	Chlorbromuron	Maloran	runoff insignificant to moderate	45 days	not for sandy soil (with less than 2% organic content)

Table 6-8 continued

Chemical Group	Common Name	Tradename	Leaching Characteristics	Half-life of residue	Constraints to use
Ureas	Diuron	Karmex	not important in measuring losses from soil.	persistence up to one season.	not to be used where it is likely to wash or leach into contact with roots of desirable trees.
	Linuron	Lorox	not important in measuring losses from soil.	phytotoxic concentration disappear within four months.	not for sandy soil. with less than 2% organic content.
	Metobromuron	Patoran			

Figure 6-3

Flow chart of the operational sequence in the establishment of poplar plantations in eastern Ontario


YEAR 3
PLANTATION FREE TO GROW
THE FOREST CROP DOMINATES THE SITE
YEAR 2
POST PLANT TENDING
MONITORING
YEAR 1
PLANTING
YEAR 0
PREPLANT TENDING
SUPPLEMENTARY SITE PREPARATION
SITE PREPARATION
BRUSHCUT
SITE PREPARATION
HARVEST
DEVELOPED AGRICULTURAL LAND
OLD FIELD
EARLY SUCCESSIONAL
FORESTED SITE
PRELIMINARY SITE ASSESSMENT AND INTENSIVE SOIL SURVEY

with simazine without any apparent antagonistic effects.

THIOCARBAMATES: EPTC is a representative of this extremely volatile chemical group and must be incorporated into the soil to prevent excessive loss. When properly used these chemicals are extremely effective site preparation herbicides. Unlike glyphosate, EPTC does have a significant residue period that provides some additional protection once the treatment has taken effect. This is the chemical of choice when preparing large acreages.

TRIAZINES: Atrazine, cyanazine, metribuzin and simazine are symmetrical triazines. Atrazine and simazine have significant residue periods. Cyanazine or metribuzin would be chemicals of choice on sites where triazine residue problems could occur. Simazine is the most consistent of the group and produces a well-defined response at proper rates. Metribuzin may induce negative or neutral effects in year two. This chemical is readily leached in sandy soils and should be used with caution. Cyanazine does not tend to produce a well-defined response. Atrazine is much more mobile than simazine and may cause damage to plantations on light soils. Simazine is the chemical of choice for pre-plant tending.

TRIAZOLE: Amitrole is a site preparation chemical but is not as effective as glyphosate.

URACILS: Terbacil is a representative of this group. It has significant residual carry-over but can be used in place of simazine on heavier soils. On soils of low organic content damage to plantations may occur.

UREAS: Chlorbromuron, metobromuron, diuron and linuron are representatives of the ureas. They are potent herbicides with moderate residual carry-over periods and should not be used on low organic matter soils. They are very rate-dependent and produce a well-defined dosage response. Linuron produces the least consistent response of the group.

Treatment Rates and Corresponding Chemical Costs

Chemical costs listed by treatment are given in Table 6-9. These costs are in 1981 Canadian dollars and do not include the cost of application.

As a rule, the lowest rate of a particular chemical to produce a rank one response is the treatment of choice. Herbicides, if improperly used or if used without discretion, can cause significant plantation damage. The lowest possible rates are not only the safest but also the most cost effective.

If the above guideline is followed, the chosen application rates fall within the range recommended for agricultural crops.

Formulations and Method of Application

Formulations can influence the use of herbicides. Granules, for instance, can be safely applied to a site that has a standing crop.

The method of application will also have an effect on herbicide success. A post-emergent herbicide will enhanced effectiveness if it can be applied by direct

Table 6-9

Chemical treatment costs for various application rates

Chemical Name	Common Name	Tradename	Treatment Rate kg active/ha	1981 Cost/ha
Acetamide	Metolachlor	Dual	.56	$ 8.85
			1.12	17.70
			2.24	35.39
			4.48	70.78
			8.96	141.57
Amides	Alachlor	Lasso	.56	$ 6.14
			1.12	12.28
			2.24	24.44
			4.48	48.93
			8.96	97.86
	Diphenamid	Enide	.56	13.83
			1.12	27.66
			2.24	55.33
			4.48	110.66
			8.96	221.31
	Napropamide	Devrinol	.56	28.39
			1.12	56.78
			2.24	113.57
			4.48	227.14
			8.96	454.27
Glycine	Glyphosate	Roundup	1.12	$ 79.29
			2.24	158.32
Thiocarbamates	EPTC	Eptam	.56	$ 6.10
			1.12	12.19
			2.24	24.39
			4.48	48.96
			8.96	97.83
Triazines	Atrazine	Aatrex	.28	$ 1.61
			.56	3.22
			1.12	6.39
			2.24	12.79

Chemical Name	Common Name	Tradename	Treatment Rate kg active/ha	1981 Cost/ha
Triazines	Cyanazine	Bladex	.56	$ 6.43
			1.12	12.86
			2.24	25.82
			4.48	51.56
			8.96	103.20
	Metribuzin	Lexone/Sencor	.56	$ 33.16
			1.12	66.04
			2.24	132.07
			4.48	264.42
			8.96	528.84
	Simazine	Princep	.28	3.52
			.56	6.94
			1.12	13.88
			2.24	27.76
			4.48	55.74
			8.96	111.37
			.28	$ 16.35
Uracil	Terbacil	Sinbar	.56	32.70
			1.12	64.45
			2.24	128.91
			4.48	258.78
			8.96	517.08
Ureas	Chlorbromuron	Maloran	.56	$ 14.20
			1.12	28.40
			2.24	56.81
	Diruon	Karmex	.28	3.75
			.56	7.40
			1.12	14.79
			1.68	22.30
			2.24	29.59
			4.48	59.40

Table 6-9 continued

Chemical Name	Common Name	Tradename	Treatment Rate kg active/ha	1981 Cost/ha
Triazine and Triazole	Simazine and Amitrole	Amizine	.56	$ 11.60
			1.12	23.25
			2.24	46.50
			3.92	81.34

contact onto the target vegetation. Hence "wiping" or "rolling" the chemical onto the target vegetation takes precedence over spraying, especially with glyphosate. Not only will there be a savings with respect to the amount of chemical used but also there is a greater margin of safety for applications made within a standing crop.

Conclusions

This chapter illustrates how an area of agricultural technology can be adapted to forestry practice. The result is an increase in biomass production of 300 per cent to per cent, and development of suitable technology to provide for the establishment of large-scale industrial plantations of poplars.

The translation of this technology into forestry practice requires further work. When formulating herbicide prescriptions, the practitioner must take into account a sequence of controllable and uncontrollable factors: soil type, target weed populations, weed spectrum, shifts in weed populations, herbicide residues, crop sensitivity, etc. Herbicides are very efficient and effective tools. To prevent long-term plantation damage they must be used with discretion. There are no perfect prescriptions only some which are better than others.

7 CULTURAL PRACTICES

The routine establishment practices used for hybrid poplar plantations have been described in Chapter 6. There are, however, a number of cultural practices that can be used to increase productivity. These additional practices have, as yet, been limited in their application in eastern Ontario. Drainage and subsoiling can increase a soil's rooting volume and available nutrient levels on wet sites; deep planting techniques place the root system into immediate contact with the water table; cover crops prevent the development of weed competition - and nitrogen-fixing plants, used in this manner, also improve soil fertility; and fertilization may be necessary on deficient soils to improve their nutrient status. The effective use of these various techniques is dependent upon sound knowledge of the treatment methods and upon sound knowledge of the treatment methods and the associated growth responses. Technology development is currently being initiated and the work reported in this chapter is, therefore, preliminary in nature. The majority of the poplar plantations in eastern Ontario are young (less than ten years of age), and the need for ameliorative treatments has not yet become obvious. Significant lag times between treatment and growth responses are common with fertilizer treatments (Heiberg et al., 1964). In some cases the beneficial results of a treatment may not be fully recognized until as late as the second rotation (Ballard, 1978).

Drainage

The primary objective in drainage is to remove excess surface water. Areas with standing water over extended periods of the growing season have poorly aerated soils. Excess moisture increases the mobility of herbicide residues such as simazine; the residue is taken up by the trees, resulting in damage and mortality.

Drainage is one of the few techniques that results in an immediately visible improvement in the site. Improved soil aeration results in increased soil rooting volume and the accumulated organic matter on these sites contains a large nutrient pool. Drainage improves the rate of organic decomposition and, as this occurs, the released nutrients become available for tree growth. Proper drainage can result in increases in volume production of 100 per cent or more (Zon and Averell, 1928). Drainage can be improved by establishing a network of primary, secondary and tertiary drains on the site. In contrast to agriculture, where drains must reduce the height of the water table to allow tile drainage, the objective for poplars is to move only the excess surface water from the site. Therefore the requirements for suitable outlets and drain depths are less critical.

Tertiary drains are small shallow ditches that cross the property. These shallow drains can be created carefully ploughing double furrows during site preparation. The Maletti Rotary Ditcher (registered trademark) has been tested in eastern Ontario for the construction of tertiary drains. A ditch 30 cm deep and 100 m long can be excavated in 10 minutes. However, this machine is easily damaged and not suitable for stony sites.

A series of secondary drains deliver the water to a large primary drain. Larger drains are constructed using tractor mounted backhoes. The cost of primary drain construction is quite high and can only be justified by adequate growth increases.

Maintenance of an existing drainage system is important; beavers and muskrats can seriously damage drainage systems and increase maintenance costs. In Lanark County up to 20 per cent of the most productive forest land has been flooded by beavers (personal communication - J. McCready, Forests Supervisor, Carleton Place District). In Dundas County, 22 per cent of the landbase is classed as very poorly drained; poorly drained land makes up an additional 36 per cent of the county (Matthews and Richards, 1952). With proper drainage, many of these sites would be highly productive for fast-growing hardwoods.

Subsoiling

In many areas of eastern Ontario the B and C horizons of the soil consist of highly compacted basal tills. Bulk densities of 1.8 g/cm^3 or higher are common in these materials. Drainage and soil rooting volume are restricted by compacted lower soil horizons. In some areas the appearance of the surface vegetation is very similar to that of vegetation growing on soils classed as shallow to bedrock.

The root growth response to a loosened lower soil profile after one year was examined for clone 'I-45/51', at seven years of age, growing in an imperfectly drained clay loam till with compact B and C horizons. The soil was loosened by individually excavating the profile horizons from pits adjacent to several trees and then carefully replacing the soil. After one year the pits were re-examined to compare adjacent disturbed and undisturbed profiles. The mass of roots per unit volume (gm/cm^3) was determined by excavating and sifting the roots from five sample volumes of 2.70×10^3 cm^3 of soil from each horizon in both the disturbed and undisturbed profiles. Table 7-1 gives the bulk density values and grams of roots per cm^3 for each profile.

All roots were removed from the disturbed profile during the initial excavation, therefore any roots observed in this profile during the second excavation represented new growth. The average weight of fine roots was considerably greater for each horizon in the disturbed profile. The undisturbed profile contained a great amount of large roots. Fine roots developed very rapidly in the disturbed soil so that the total weight of roots per cm^3 was similar for both profiles. A paired t-test indicated that the differences in large

Table 7-1

Root growth response of seven-year-old 'I-45/51' to a loosened genetic hardpan after one year

Horizon	Undisturbed profile				Disturbed profile			
	Bulk Density g/cm^3	Weight of Roots Per Unit Volume (g/cm^3)x10			Bulk Density g/cm^3	Weight of Roots Per Unit Volume (g/cm^3)x10		
		Large	Fine	Total		Large	Fine	Total
A	1.28	4.47	18.68	23.15	1.04	0	30.02	30.02
B	1.39	6.44	5.48	11.92	1.24	0	11.15	11.15
C	1.79	3.2	2.81	6.01	1.66	0	9.67	9.67

roots and fine roots in the B horizon were significant at the five per cent level. The bulk density values were lower in the disturbed profile, but this was not significant. Broadfoot and Bonner (1966) found that for Populus deltoides Bartr. (eastern cottonwood) root growth was inhibited at a bulk density greater than 1.4 g/cm^3. There is, therefore, a possibility for root response to loosening of the subsoil where the bulk density exceeds 1.4 g/cm^3.

A trial was also initiated to examine the effects of subsoiling on the growth of clone 'DN 70' on a compact, imperfectly drained, clay loam till soil. Subsoiling was carried out to a depth of 1 m using a single-tooth asphalt ripper mounted on the back of a back of a bulldozer. The subsoiling was carried out in October 1978 prior to planting in the following spring.

The average bulk density of the soil then was 1.7 g/cm^3 and 1.82 g/cm^3 for the B and C horizons respectively. Trenching, using the ripper tooth, was carried out in parallel traverses at 3 m and 6 m spacings. Clone 'DN 70' was planted over the area without regard to the position of the trenches.

After two years of growth, average diameter, cumulative plot height and survival on the control (nonsubsoiled) areas, and the areas subsoiled at 6 m intervals, were significantly greater than on the 3 m spaced subsoiled areas (Table 7-2). The differences in subsoiling were also associated with differences in weed control. Weed competition was observed to increase as the subsoiling spacing decreased. Effective weed control by simazine depends upon a uniform and continuous concentration of chemical residue near the soil surface. Mechanical soil disturbances disrupt this layer of residue and allow weed growth. As the intensity of the subsoiling is increased, a larger soil area is disturbed, greatly reducing the effectiveness of the herbicide. In future work, subsoiling must be more appropriately scheduled within the sequence of site preparation operations.

A considerable improvement in drainage of the site was observed in association with the subsoiling and drainage operations. The subsoiling tended to act as a form of tertiary drainage. This trial will be monitored for changes which may occur as the trees mature and more mature and more fully exploit the available soil rooting volume. Jobling (1961) observed increased growth in poplar planted on compact soils when dynamite was used to create planting pits. The blast tended to loosen the soil for a considerable distance around the planting hole.

Table 7-2

Response of clone 'DN 70' to subsoiling treatments at two intensities

Subsoiling Spacing	Average Height (m)	Cumulative Plot Height (m)	Average Diameter (cm)	Per cent Survival
Control (none)	282.4a	5925a	20.43a	84%a
3 m	153.3a	1658b	6.34b	44%b
6 m	263.2a	5792a	17.25a	89%a

Values are for growth and survival two years after treatment. Subsoiling spacing is the spacing between parallel passes of a bulldozer mounted with an asphalt ripper operating to a depth of 1 m. Values adjacent to a common letter are not significantly different at the five per cent level.

Sludge Utilization

Sludges from industrial processes and the treatment of municipal sewage pose major disposal problems. Environmentally acceptable methods for disposing of these materials are limited and costly. Many sludges are high in nutrients and relatively free of toxic contaminants. The recycling of these materials into plantations represents an environmentally acceptable disposal method. The sludges currently being tested in fast-growing hardwood plantations are well within the quality guidelines established by the Ontario Ministry of the Environment (1980). The rates of application being tested are also well within the guidelines governing the agricultural use of sludges on food producing land. Therefore, the build-up of toxic levels of heavy metals in the soil is prevented by careful monitoring. The elemental analysis of two sludges currently in test in eastern Ontario is given in Table 7-3.

The permissible application levels for various elements and the amount of sludge per hectare that would be required to exceed these levels are listed in Table 7-4. The Dupont material is an activated sludge that results as a by-product of several chemical processes. It is characterized by a high organic nitrogen content. The Domtar material is a clarifier sludge resulting from the paper-making process. This sludge is primarily organic and consists of pulp fibres and fine clay materials used in the finishing of fine paper. The Dupont sludge has low concentrations of major nutrient elements but does provide a major addition of organic matter. The addition of organic matter is most useful where the objective is to increase the cation exchange capacity and moisture-holding capabilities of a soil. The Domtar sludge contains even lower concentrations of major nutrients. The results of applying Dupont sludge to plantations on different sites at varying rates are given in Tables 7-5 and 7-6. Domtar sludge has also been tested at rates of 5.1, 6.4 and 12.8 tonnes per hectare. In all cases, there have been no significant differences in growth and survival observed among the various treatments.

The relatively low rates of application may not have been sufficient to cause a significant impact on growth. Only a small percentage of the total organic nitrogen in the Dupont sludge would become available during the first growing season. Domtar sludge rates would also need to be much higher in order to significantly increase the organic matter levels in the soil (personal communication - K.A. Armson, Chief

Table 7-3

Elemental analysis of sludges tested in fast-growing hardwoods

Element	Dupont Sludge Analysis A* PPM or %	Dupont Sludge Analysis B* PPM or %	Domtar Clarifier Sludge PPM or %
Total N	9.1%	10%	71.0
Carbon	49.1%		
Hydrogen	6.9%		
Oxygen	8.5%		
Phosphorous	1.0%	1.5%	503.3
Arsenic	0.21		
Cadmium	0.13	0.13	2.3
Calcium		2.2%	12.2
Cobalt	16.0		
Chronium	18.0	16.3	22.0
Copper	185.0	330.0	71.0
Iron			2990.0
Molybdenum	4.6		
Nickle	4.8	7.5	
Lead	2.9	7.5	55.3
Selenium	0.19		
Zinc	17.0	30.0	87.7
Sodium	7.8%		1110.0
Boron	250.0	170.0	
Magnesium			2490.0
Manganese	17.0	190.0	335.7
Potassium	0.24%	0.6%	
Mercury	0.09		
Magnesium		0.8%	
NO_3	0.4		17.7
NH_4		1.6%	0.1
Nitrite			0.2
Total Solids	10.13%	9.6%	25.0%
pH	8.0		8.25

All values in PPM unless per cent is indicated.

* Sludge Analysis A by Dupont Inc. Sludge Analysis B by the Universities of Guelph and Toronto. Domtar Sludge analysis by Domtar Inc.

Table 7-4

Heavy metal content of Dupont and Domtar sludge compared with Ontario guidelines for sludge utilization on agricultural land

	Acceptable Heavy Metal Additions *		Elemental Analysis and Maximum Permissible Sludge Application within Guideline for Each Element			
			Domtar		Dupont	
Element	Maximum Acceptable Metal Addition to Soil (kg/ha)	Maximum Acceptable Metal Concentration in Sludges and Compost Containing 5%N or less* (ppm)	Maximum Concentration in PPM*	Maxiumum Sludge Application Within Guidelines kg/ha	Maximum Concentration in PPM	Maximum Sludge Application Within Guide lines kg/ha
Arsenic	14.0	70.0			.21	66,666,667
Cadmium	1.6	10.0	2.3	695,652	.13	12,307,692
Cobalt	30.0	150.0			16.0	1,875,000
Chromium	210.0	1000.0	22.0	9,545,455	17.2	12,209,302
Copper	150.0	750.0	71.0	2,112,676	257.5	582,524
Mercury	0.8	4.0	1.3	615,385	0.09	8,888,888
Molybdenum	4.0	20.0			4.6	869,565
Nickel	32.0	160.0			6.2	5,161,290
Lead	90.0	450.0	55.3	1,627,486	5.2	17,307,692
Selenium	2.4	12.0			0.19	12,631,579
Zinc	330.0	1650.0	87.7		23.5	14,042,553

Maximum permissible sludge application on the basis of each individual elemental concentration is calculated on the basis of these guidelines.

* Ontario Ministry of the Environment, 1980

Table 7-5

Results of applying Dupont sludge to an eight-year-old clone '1-45/51' at various rates

Application Rate kg Oven Dry Sludge/ha	Application Rate kg Nitrogen/ha	Average Height Fall 1980 (m)	Height Growth since Treatment	Average dbh Fall 1980 (cm)	Diameter Growth since Treatment (cm)	Per cent Survival Fall 1980	Change in Per cent Surviving since Treatment
0	0	9.51	2.26	11.5	3.5	73	-2
932	89	11.39	2.93	13.5	2.5	83	-1
1864	178	10.59	2.87	12.5	2.5	84	0
3728	356	10.44	2.73	12.0	2.5	80	0

The sludge was applied in May 1979. The plantation was established at 3 m x 3 m spacing on an imperfectly drained clay loam till.

Table 7-6

Results of applying Dupont sludge during the second year of growth to clone 'DN 33' at various rates

Application Rate Kg Oven Dry Sludge/ha	Application Rate kg Nitrogen/ha	Average Height Fall 1980 (m)	Height Growth since Treatment	Average dbh Fall 1980 (cm) *	Per cent Survival	Change in Per cent Surviving
0	Control	3.11	1.56	1.76	70	-2
3403	325	3.11	1.77	2.06	72	-1
6806	650	3.03	1.83	1.91	71	0
13612	1300	2.95	1.70	1.[illegible]7	62	0

The sludge was applied in May 1980. The plantation was established at 3 m x 3 m spacing on an imperfectly drained clay loam till.

* Initial Pre-treatment diameter not measured because of small tree size.

Forester, Province of Ontario, 1979). The rates of application could be increased several times without exceeding the environmental guidelines.

Deep Planting

Most plantations in eastern Ontario have been established using 25cm long, unrooted cuttings. However, deep planting offers the advantage of planting the root system deep into the soil and often in direct contact with the water table. The trees tend to develop a multi-tier root system and rapidly exploit the soil rooting volume. The deep planting of 2+0 fast growing hardwoods planting stock is being tested on a number of sites. This is the accepted practice in European poplar culture where planting depths of 2 m to 3 m are used.

Figure 7-1 shows the development of a root system of clone 'DN 17' after two years on a rapidly drained sandy loam over loamy sand. Figure 7-2 shows the same clone at the same age, but growing on an imperfectly drained clay loam. The root system of the tree on the imperfectly drained soil tends to be more concentrated in the upper profile. On the drier site, the root system is more extensive. Deep planting has facilitated the rapid adaptation of the root system to two textural conditions.

Deep planting is most commonly used in long rotation plantations for veneer production and in line plantings for windbreaks and amenity purposes. Tending is carried out using herbicides or by dual cropping the area.

Figure 7-1

Root system of deep planted 'DN 17' two years after planting on a well-drained sandy loam, over loamy sand

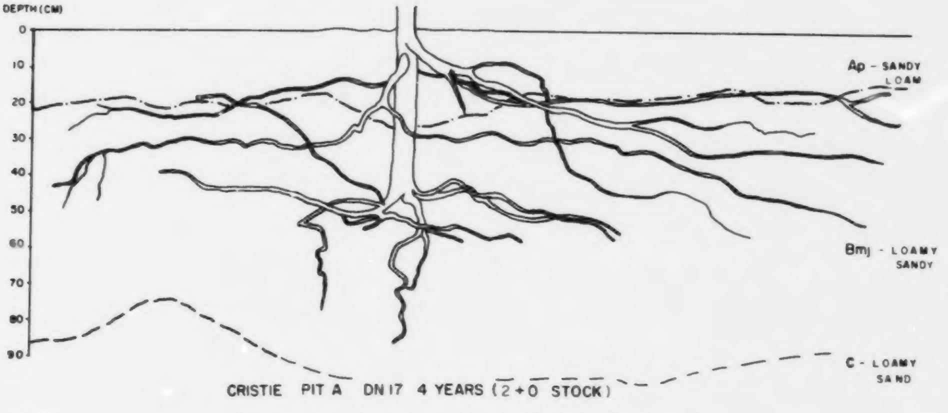
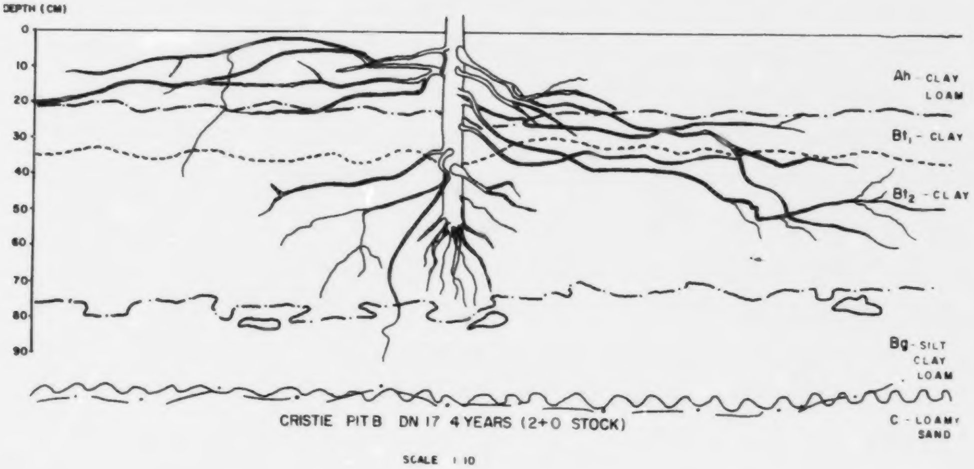

DEPTH (CM)
0
10
20
30
40
50
60
70
80
90
Ap - SANDY LOAM
Bmj - LOAMY SANDY
C - LOAMY SAND
CRISTIE PIT A DN 17 4 YEARS (2+0 STOCK)
SCALE 1:10

Figure 7-2

Root system of deep planted 'DN 17' two years after planting on an imperfectly drained clay loam, over clay


DEPTH (CM)
0
10
20
30
40
50
60
70
80
90
Ah - CLAY LOAM
Bt₁ - CLAY
Bt₂ - CLAY
Bg - SILT CLAY LOAM
C - LOAMY SAND
CRISTIE PIT B DN 17 4 YEARS (2+0 STOCK)
SCALE 1:10

Water table was at 105 cm depth in August.

Dual and Cover Crops

Often when deep planting is used to establish low density plantations, other crops or species may be planted at the same time for other purposes. The trees benefit from the tending given to the agricultural dual or cover crops planted between the rows. These crops also provide an immediate return from the plantation.

Many common vegetable species have been used as dual crops in eastern Ontario. Corn tends to be the most successful. In the Sunderland dual crop, at 5 m x 6 m tree spacing, the corn yields were observed to decrease dramatically at age four. Once the regular crop yields began to decline, the emphasis was shifted from the dual crop to various cover crops (Table 7-7) to provide weed control. The species used are currently being tested for their ablity to survive and grow under partial shade in long rotation plantations.

Red clover and alfalfa appear to be the most successful cover crops examined to date. These crops are able to grow under partial shade and form high density stands preventing the growth of weeds. Legumes offer the additional benefit of increasing the nitrogen status of the site through nitrogen fixation. Nitrogen-fixing plants may contribute from 30 to 200 kg nitrogen per hectare per year (Davey and Wollum 1979). Alnus rubra Bong. (red alder) has been reported to fix as much as 320 kg nitrogen per hectare per year (Newton et al., 1968). A number of populations of Alnus and other nitrogen-fixing tree and shrub species are being evaluated in eastern Ontario for use in mixed plantings with other fast-growing hardwoods, including poplars.

Table 7-7

Nitrogen-fixing cover crops used in dual crops in eastern Ontario

Woody	
Alder - european black	Alnus glutinosa (L.) Gaertn.
- red	Alnus rubra Bong.
- speckled	Alnus rugosa (Du Roi) Spreng.
Buffaloberry	Shepherdia argentea (Pursh) Nutt.
Lespedeza	Lespedeza spp. Michx.
Olive - autumn	Elaeagnus umbellata Thunb.
- russian	Elaeagnus Angustifolia L.
Siberian peashrub	Caragana arborescens Lam.
Herbaceous	
Alfalfa	Medicago sativa L.
Clover -red	Trifolium pratense L.
-sweet	Melilotus spp. Mill.
Lupine	Lupinus perennis L.
Trefoil	Lotus corniculatus L.

Fertilization

The fertilization of fast-growing hardwoods is a complex area in which studies are just beginning. The major program emphasis in the past has been on developing successful plantation establishment techniques. Fertilization has not been required as an establishment technique. The soils of eastern Ontario are fine textured and generally associated with adequate levels of most nutrients. But in some situations, in which soil nutrient levels have been depleted, there may be considerable opportunity to enhance growth.

Very little reliable data exists for fertility trials of fast-growing hardwoods in eastern Ontario. Ogar (1981 a,b) examined the interactions of clone, site, plant density and fertility. The two clones, 'I-45/51' and 'DN 17', exhibited different response patterns to plant density and fertility. 'I-45/51' tended to show a more positive response to increased fertility. Future fertility work in eastern Ontario will have to consider clone as well as site, density and age differences.

Conclusion

The various cultural practices described in this chapter have only been used to a limited extent in eastern Ontario. However, the poorly drained nature of the land base provides considerable opportunity to immediately use drainage as a cultural practice to improve productivity. Other practices, such as fertilization, will require longer periods of development. As the area of established plantations increases and more experience is gained in tending these stands, more emphasis will be placed on developing the cultural practices necessary to increase yields.

8 HARVEST AND YIELD

Yield is the result of the management of growth as regulated by density, time and culture. The quality and intensity of cultural practices in the first rotation period will determine the quality and quantity of regeneration after harvest. Improved culture should lead to improved yields in the future.

Three major topics will be dealt with in this chapter:

1. Silvicultural criteria for hybrid poplar harvesting systems.
2. Past, present and projected yields for specific hybrid poplar management systems.
3. The quality and quantity of coppice regeneration in a hybrid poplar plantation following harvest.

Silvicultural Criteria for Hybrid Poplar Harvesting Systems

Populus species, as well as other fast-growing hardwoods such as Alnus, Betula and Salix, regenerate primarily by coppicing or suckering from a cut stump or disturbed root system. Therefore, following harvesting, the condition of the stump and root system is of primary importance. Harvesting systems must reflect biological and silvicultural considerations in order to maximize regeneration success.

At harvest, damage to the stump has to be minimized. A clean, smooth cut must be ensured, with no ripping of stump bark. The tree must be cut close to the ground, since the most vigorous stems originate from dormant buds below the root collar (Smith, 1962). Lateral damage to the stump should be minimized to avoid root damage.

Preferably, harvesting should take place during the dormant season, to maximize the coppice and sucker productivity from the root system and to ensure that all leaves are returned to the site prior to harvesting. The leaves constitute between 10 (larger trees) and 50 (smaller trees) per cent of the green weight of the tree. A clear-cut operation is required for maximum coppicing success. Competition with residual trees decreases the productivity of coppice regrowth. Whole tree chipping operations provide suitable conditions for regeneration since all branch material is removed from the site. The equipment used for harvesting must have good manoeuvreability in order to minimize root system damage. Soil disturbance must also be minimized. Low vehicle ground pressure will reduce soil compaction, especially on more sensitivie sites such as organic soils. Limiting the number of equipment passes through the stand will reduce rutting and compaction damage.

Past, Present and Projected Yield

The net result of the management input into the establishment and tending of a plantation is the harvestable yield in terms of volume or biomass per unit area.

Three management systems have been employed in eastern Ontario - mini, midi and short rotation (Raitanen, 1980). A more appropriate terminology for these management systems is: System 35K (mini); System 4K (midi); System 1K (short). The number in each term is the density of trees per hectare. In this chapter, each system will be characterized and actual and projected yields will be presented.

System 35K

System 35K is a high-density (35 000 plants per hectare), high yielding biomass production system. Production plantations have been established at 1.0 x 0.3 m spacing, and are cut after three years for the first rotation and subsequently harvested every two years.

The production of biomass from such a plantation is related primarily to the quality of the site and intensity of management. The management of stool beds at the Kemptville Nursery, using irrigation and fertilization, represents the highest level of intensity in management input and site quality. In field plantations, good weed control is essential for high yields. The suitability of any one particular clone to dense plantations must also be considered in the clone-site allocation process. Figure 8-1 depicts the three year average height growth of three clones grown at varying densities within a randomized block trial at Leeds 69. Clone 'AK 30' performed significantly better in the denser plantings. Clone 'DN 2' showed little variation in growth, between the closer and wider spacings. Clone 'D 38' grew significantly less at closer spacings in comparison to wider spacings.

The wide variation in yields from system 35K plantations reflects the variation in intensity of management applied in the past and the limited knowledge of the genetic material most suited for high density plantations. This variation is shown in Table 8-1, which summarizes biomass yields in oven dry tonnes per hectare per year (ODT/ha/yr) from several system 35K

Figure 8-1

Average height growth for three clones grown at varying densities after three years at Leeds 69

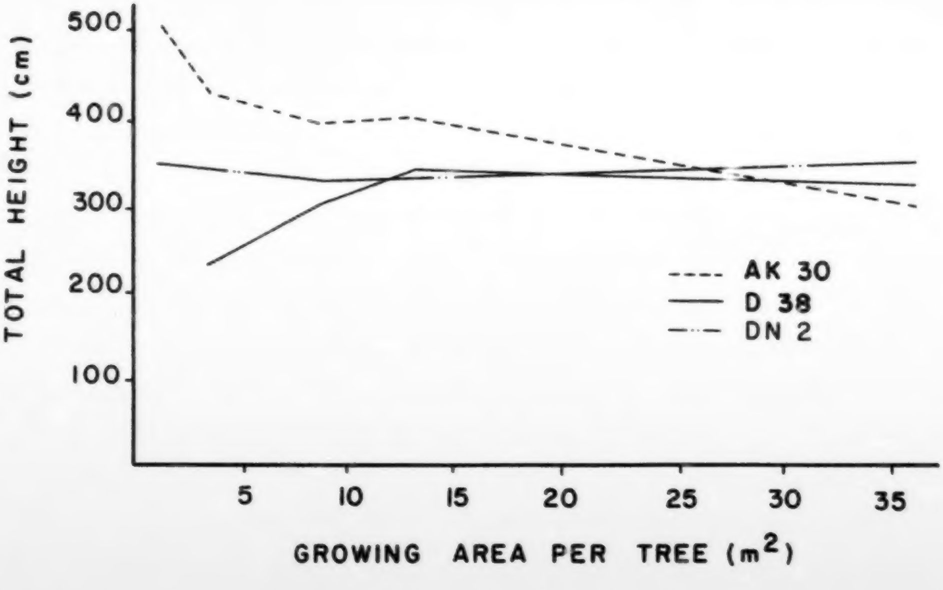


Table 8-1

Biomass yields and site information from four system 35K production plantations in eastern Ontario

	Sites			
Clone	Leeds 69	Grenville 32	Grenville 34	Edwardsburgh Land Assembly Compartment 92
AK 30	28.72			
AS 34	31.02			
C 147			10.39	1.68
D 38	2.42			
DN 1	15.08			13.75
	39.45			5.55
	5.98			
DN 2	9.17	4.16		5.21
	3.17			
DN 9	9.72			
DN 16	6.66		7.94	
DN 17		5.97		
DN 19	2.51			
DN 22	9.30			
DN 38			4.63	
DN 55			7.21	
DN 70			8.01	
DN 74		6.05	14.00	
DTAC 1				13.10
DTAC 2			11.60	
145/51		5.24		1.47
165A	8.75			

* * * * * * * * * *

Year established	1978	1977	1978	1980
Age of material when harvested	3	3	3	2
Rotation	1st	1st	1st	1st
Establishment (stock type)	cuttings	cuttings	cuttings	1+0 rooted
Site:				
Texture	loam	loamy sand	sandy loam	sandy loam
Drainage	moderately well	moderately well to well	imperfect	imperfect to moderately well
Location	Westport, Ontario	Kemptville, Ontario	Kemptville, Ontario	Prescott, Ontario

Values expressed are oven-dry tonnes of biomass per hectare per year.

production plots in eastern Ontario. In contrast, Table 8-2 summarizes biomass yields from several stool beds at Kemptville Nursery. The extreme differences in biomass yields between the stool beds and the field plots reflects the objectives of the nursery manager to increase the growth of the stools and to maximize the production of cuttings by fertilization, weed control, irrigation and pest control. In the future, the variation in yield will be reduced as the technology of biomass production is developed. Raitanen (1980) estimated an average productivity of 16.0 ODT/ha/yr. With increased intensity of management and improved genetic material, it is anticipated the upper limit of productivity will increase.

Table 8-2

Biomass yields from Kemptville Nursery stool beds

Clone	Age of Stool (years)	Yield (ODT/ha/yr)
NM 6	2 1/2	29.28
NM 6	2	25.60
NM 6	1 1/2	15.68
NM 1	1 1/2	10.96
DTAC 9	1 1/2	12.00
DN 173	1 1/2	11.12

Values expressed are oven-dry tonnes of biomass per hectare per year.

System 4K

System 4K is an intermediate density (4 000 plants per hectare), high yielding biomass production system.

Plantation spacing is 1.5 m x 1.5 m. To date, system 4K plantings have been used in development trials throughout the region. As discussed in Chapter 2, a rotation of five years should maximize yield under system 4K management. A yield of 8.35 ODT/ha/yr has been projected for future eastern Ontario system 4K plantations (Raitanen, 1980).

System 1K

System 1K is a low density (1 000 plants per hectare), fibre production system and represents the largest percentage of poplar production plantings in eastern Ontario. The most commonly used spacing to date has been 3.0 m x 3.0 m, although a slightly wider spacing (i.e., 3.6m x 3.6m) is currently under examination. Depending on the productivity of the site and the clone, a rotation of eight to 12 years is anticipated.

The majority of older plantations in the region (i.e., established between 1972 and 1975) were established with a limited number of clones. Clones 'I-45/51' and 'DN 17' were represented in 80 per cent of the plantings of this time period. The performance of 'DN 17' and 'I-45/51' has proven average in comparison to newer genetic material brought into the program. These clones ('DN 17' and 'I-45/51') are now used as a standard for comparison in eastern Ontario.

A demonstration harvest of short rotation hybrid poplar was conducted at Leitrim property near Ottawa. A 0.4 ha plot was cut using a whole-tree harvesting system (feller buncher, grapple skidder, on-site chipper). The yield of the predominately hybrid aspen stand is represented in Table 8-3.

Four older production plantations were selected for yield studies - two plantations of 'I-45/51' and two of 'DN 17'. Table 8-4 summarizes the management history of each site. Stem analysis data, in conjunction with inventory information, was used to construct standard volume and weight equations and tables for each clone. Based on the standard volume and weight tables, local volume tables were derived. Normal yield tables were produced for each site for comparative purposes. The following provides a more complete description of the derivation of the volume and yield tables.

Based on stand data, 37 trees encompassing the range of height and diameter classes were selected for each clone at Domtar 1 for detailed stem analysis. Stem analysis data included height increment per year, diameter increment per year at the mid-point of each internode and diameter increment per year at DBH (1.3 m).

The sample of 37 trees per clone was selected for green weight, total tree weight (with and without leaves), bole weight, branch weight and leaf weight. This information was used to derive stand volume and biomass data. Ten trees were selected, at both SNA 66 and Codrington, represent- ative of the range of heights and diameters in the plantations. Measurements of the height increment per year and diameter increment at DBH were taken. Local height over diameter curves were generated for each site. Table 8-5 summarizes the derived equations. Figure 8-2 shows mean annual increment (MAI) and current annual increment (CAI) trends for each site.

Table 8-3

Yield of hybrid poplar biomass
from a demonstration harvest in Ottawa 1977 (Leitrim)

Stand Features at Harvest	
Species	Populus Leuce Section (hybrid aspens)
Age (at harvest)	6 1/2 years
Year established	1971
Spacing	3.6 m x 3.6 m
Diameter (DBH) at harvest	13.1 cm
MAI (6 1/2 years)	2.9 ODT/ha/yr
Projected MAI (at 10 years)	3.8 ODT/ha/yr

Table 8-4

Management history of four sites for yield study

	Codrington	SNA 66	Domtar 1	Domtar 1
Clone	'I-45/51'	'DN 17'	'I-45/51'	'DN 17'
Year Established	1974	1974	1975	1975
Stems/ha	760	1000	1000	1000
Spacing	3.6 m x 3.6 m	3.0 m x 3.0 m	3.0 m x 3.0 m	3.0 m x 3.0 m
Age (1980)	7	7	6	6
Location	Brighton	Plantagenet	Avonmore	Avonmore
Soil texture	Silt Loam	Fine Sandy Loam	Clay Loam	Clay Loam
Soil drainage	Moderately well drained	Imperfectly/ moderately well drained	Imperfectly drained	Imperfectly drained

Table 8-5

Equations for estimating height as a function of diameter (DBH) for clones at four locations

Site	Clone	Equation	r^2
Codrington	I-45/51	$Ht(m) = 1.843D^{0.679}$	0.966
SNA 66	DN 17	$Ht(m) = 2.574D^{0.644}$	0.905
Domtar I	I-45/51	$Ht(m) = 2.555D^{0.571}$	0.967
Domtar I	DN 17	$Ht(m) = 2.768D^{0.555}$	0.966

Equation expresses total tree height (Ht) in metres. Diameter (D) is expressed in cm at DBH (1.3 m, outside bark).

Figure 8-2a

MAI and CAI trends for clone 'I-45/51' at Codrington

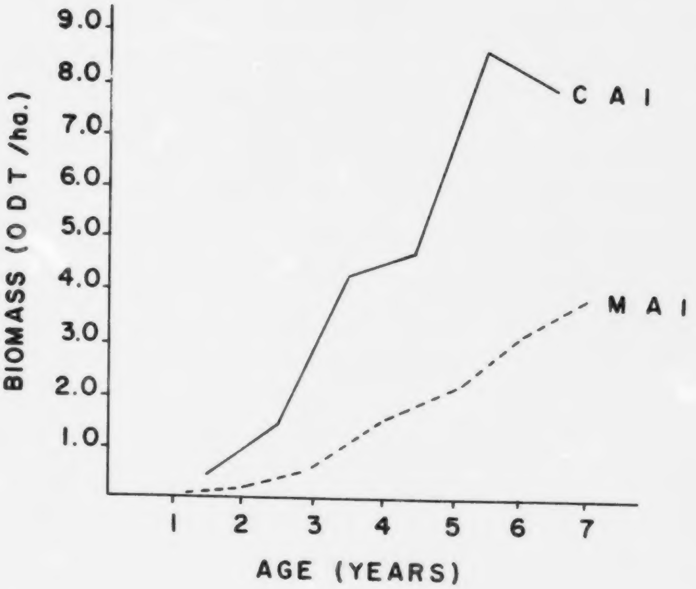


Figure 8-2b

MAI and CAI trends for clone 'I-45/51' at Domtar I

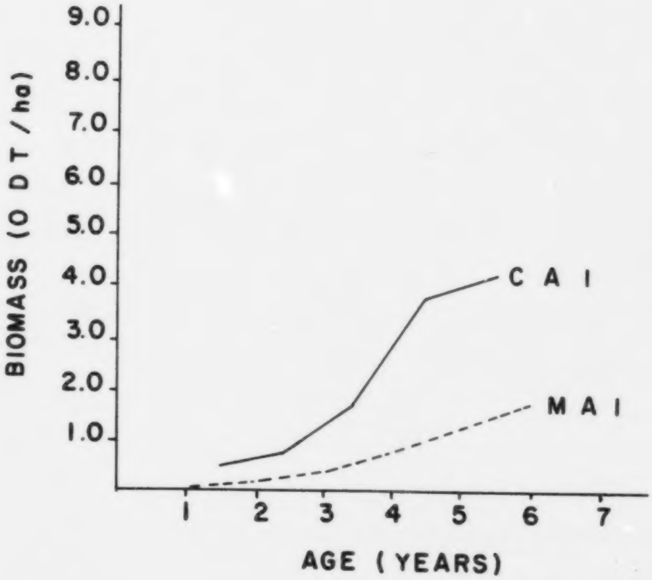


Figure 8-2c

MAI and CAI trends for clone 'DN 17' at SNA 66

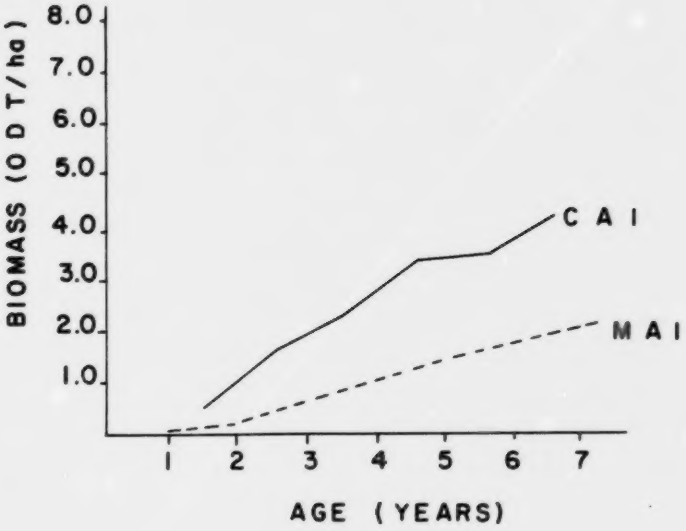
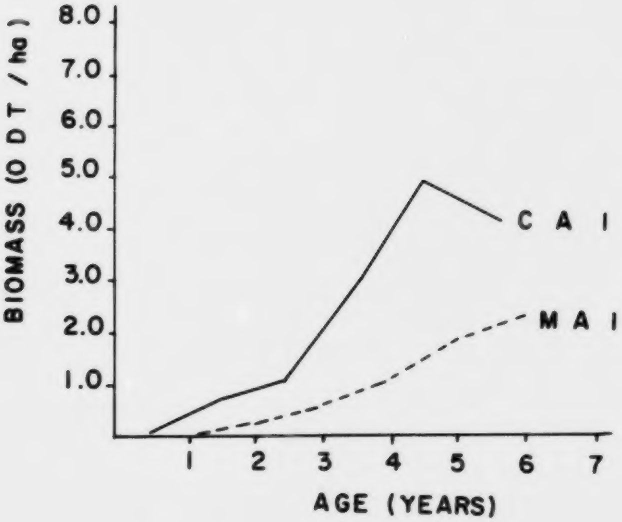


Figure 8-2d

MAI and CAI trends for clone 'DN 17' at Domtar I



'I-45/51' has produced an MAI of 3.95 ODT/ha/yr in seven years at Codrington and the CAI reached maximum at year 6 (Figure 8-2a). Assuming that there will be a reduction in CAI, a rotation of nine years with an MAI of 5.0 ODT/ha/yr, or a harvest yield of 45.0 ODT/ha could be expected. On the Domtar 1 sites (Figures 8-2b and 8-2d) the CAI for 'I-45/51' reached a maximum between years five and six. For clone 'DN 17', the CAI peaked at five years. At both sites, a final harvest MAI of 3.0 ODT/ha/yr appears likely. Figure 8-2c shows 'DN 17' is growing steadily at SNA 66, as indicated in the CAI curve. The trend suggests a ten or eleven year rotation age.

Comparison of System 1K Spacings

As previously stated, 3.0 m x 3.0 m spacing has historically been used for the establishment of the low density fibre production systems (system 1K) in eastern Ontario. Spacing studies with *Populus deltoides* Bartr. (eastern cottonwood) in the southern United States have shown increased growth and yield in plantations established at 3.6 m x 3.6 m compared to 2.7 m x 2.7 m spacings (Krinard, 1975).

Volume and whole tree (excluding leaves) biomass weight equations were generated from the Domtar 1 stem analysis work (Table 8-6). These equations were used to generate standard volume and biomass weight tables for DN 17 and I-45/51. These tables are presented in Appendix 5. Figures 8-3 to 8-6 represent regression curves derived from the equations.

Local volume tables for each site were prepared using the stem analysis data, inventory information and yield equations to determine the yield increment for

Table 8-6

Volume and biomass equations - clones 'DN 17' and 'I-45/51' in eastern Ontario

Clone	Parameter*	Equation	r^2
DN 17	Volume	$V\ (cm^3) = 945.214 + 0.290X$ $(X = D^2H \text{ in } cm^3)$	0.969
	Weight	$W\ (kg) = 0.993X^{0.762}$ $(X = D^2H \text{ in '000 } cm^3)$	0.986
I45/51	Volume	$V(cm^3) = 1245.413 + 0.275X$ $(X = D^2H \text{ in } cm^3)$	0.965
	Weight	$W\ (kg) = 0.668X^{0.813}$ $(X = D^2H \text{ in '000 } cm^3)$	0.989

* Volume expressed in cm^3 / tree (volume of bole from stump to tip calculated using Smalian's formula). Weight expressed in kg per tree green (weight of whole tree excluding leaves). Diameter at DBH (1.3 m).

Figure 8-3

Regression of volume for 'DN 17'

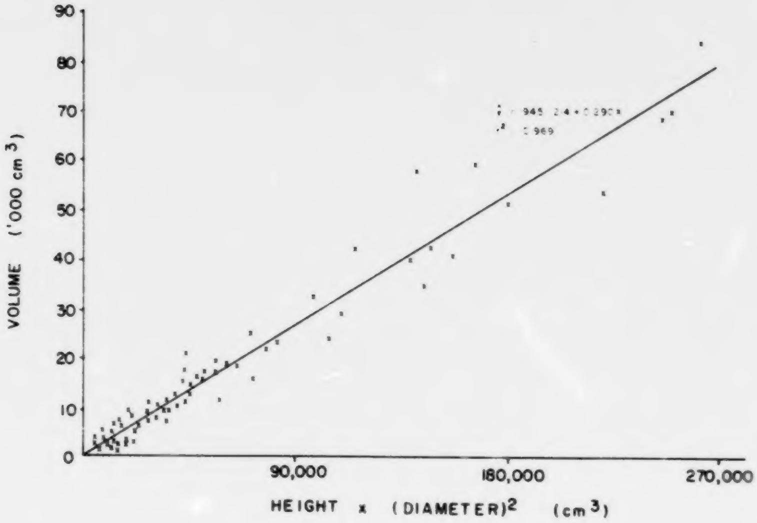


Figure 8-4

Regression of green weight (whole tree) for 'DN 17'

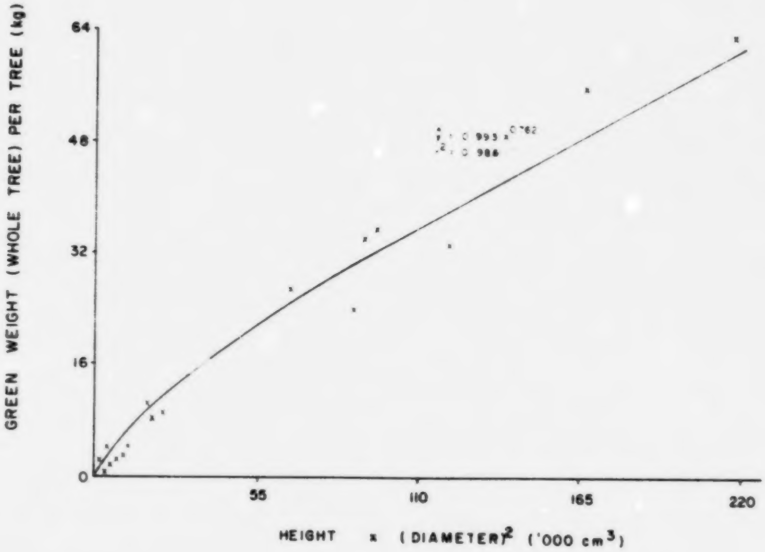


Figure 8-5

Regression of volume for '1-45/51'

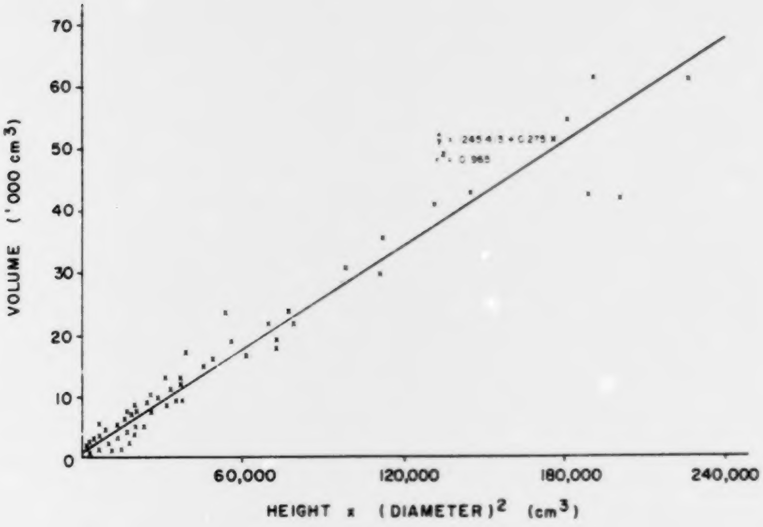
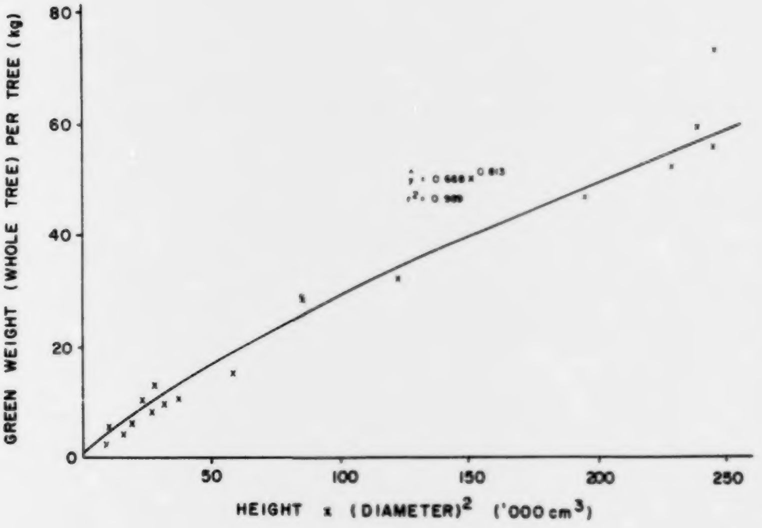


Figure 8-6

Regression of green weight (whole tree) for '1-45/51'



each year since establishment. Normal yield tables were prepared for each location (Tables 8-7, 8-8, 8-9 and 8-10). The normal yield tables form the basis for the comparison of sites.

A comparison was made of six years of cumulative growth of clone 'I-45/51' at Codrington and Domtar 1. Codrington was established at 3.6 m x 3.6 m spacing (13.0 m^2 per tree). Table 8-11 summarizes and compares six years of growth data from these two locations. Figures 8-7 to 8-10 present a comparison of sites in terms of height, diameter, volume and weight increment over time. The following features should be noted:

1. Tree height is a widely accepted indicator of site quality for tree growth. Therefore, in examining the height data presented in Table 8-11 it can be deduced that the Codrington site supports significantly better tree growth than Domtar 1.
2. Differences in spacing have negligible effects on height growth. Height growth trends in Figure 8-9 and those reported by Krinard (1975) support this statement.
3. Changes in diameter have been cited as reflecting increased spacing or growing area per tree. Table 8-11 shows a difference of 5.1 cm or 59 per cent in diameter growth between the Codrington and Domtar sites.

To differentiate between the variation in diameter due to site and that due to spacing, the height and diameter of an average tree at Domtar 1 growing at the same rate of height growth as 'I-45/51' at Codrington must be derived. Therefore, using a local height-diameter equation for Domtar, a diameter of 12.66 cm can be computed. The difference between the diameter at Codrington (13.71 cm) and Domtar 1 (12.66cm) probably

Table 8-7

Yield Table for '1-45/51' at Codrington*

Age (years)	Average Diameter (cm. at 1.3m)	Average Height (cm)	Basal Area/ha (m)	Volume (m/ha.)**			Weight (ODT/ha)***		
				Total	CAI	MAI	Total	CAI	MAI
1	--	90	--	--	--	--	--	--	--
					1.39			0.44	
2	.17	312	0.28	1.39		0.69	0.44		0.22
					2.04			1.44	
3	.64	523	1.28	3.43		1.14	1.88		0.63
					8.34			4.34	
4	.06	760	3.88	11.77		2.94	6.22		1.56
					10.77			4.75	
5	0.53	912	6.62	22.54		4.51	10.97		2.19
					22.76			8.65	
6	13.71	1090	11.22	45.30		7.55	19.62		3.27
					23.24			8.00	
7	16.02	1212	15.32	68.54		9.79	27.62		3.95

* Plantation established in 1974 at 3.6m x 3.6m spacing

** Volume of stem from stump to tip, including bark (m^3)

*** Weight (oven-dry tonnes) of whole tree excluding leaves (0.5 ODT = 1.0 green tonne).

Table 8-8

Yield table for 'I-45/51' at Domtar I*

Age (years)	Average Diameter (cm. at 1.3m)	Average Height (cm)	Basal Area/ha (m)	Volume (m/ha)**			Weight (ODT/ha) ***		
				Total	CAI	MAI	Total	CAI	MAI
1	0.20	135	0.003	0.18		0.18	0.02		0.02
					1.62			0.55	
2	2.13	393	0.36	1.80		0.90	0.57		0.29
					1.10			0.80	
3	3.27	502	0.84	2.90		0.97	1.37		0.46
					2.91			1.78	
4	4.85	629	1.85	5.81		1.45	3.15		0.79
					7.30			3.70	
15	7.02	777	3.87	13.11		2.62	6.85		1.37
					9.81			4.31	
6	8.61	874	5.82	22.92		3.82	11.16		1.86

* Plantation established in 1975 at 3.0m x 3.0m spacing.

** Volume of stem from stump to tip, including bark (m^3).

*** Weight (Oven-Dry tonnes) of whole tree excluding leaves (0.5 ODT = 1.0 green tonne).

Table 8-9

Yield Table for 'DN 17' at SNA 66*

Age (years)	Average Diameter (cm at 1.3m)	Average Height (cm)	Basal Area/ha (m)	Volume (m/ha)**			Weight (ODT/ha)***		
				Total	CAI	MAI	Total	CAI	MAI
1	--	80	--	--		--	--		--
					--			--	
2	1.50	334	0.18	1.23		1.23	0.45		0.23
					1.64			1.61	
3	2.82	502	0.62	2.87		1.44	2.06		0.69
					3.34			2.33	
4	4.52	680	1.61	6.21		2.07	4.39		1.10
					5.76			3.30	
5	6.53	862	3.35	11.97		2.92	7.69		1.54
					7.04			3.46	
6	7.72	959	4.68	19.01		3.80	11.15		1.86
					9.49			4.27	
7	9.37	1087	6.89	28.50		4.75	15.42		2.20

* Plantation established in 1974 at 3.0 m x 3.0 m spacing.

** Volume of stem stump to tip, including bark (m^3).

*** Weight (oven-dry tonnes) of whole tree excluding leaves (0.5 ODT = 1.0 green tonne).

Table 8-10

Yield Table for 'DN 17' at Domtar I*

Age (years)	Average Diameter (cm at 1.3m)	Average Height (cm)	Basal Area/ha (m)	Volume (m/ha)**			Weight (ODT/ha)***		
				Total	CAI	MAI	Total	CAI	MAI
1	0.4	140	0.013	0.10	--	0.11	0.02	--	0.02
					1.34			0.74	
2	1.7	372	0.23	1.44		0.72	0.76		0.38
					1.37			1.20	
3	3.72	574	1.09	2.81		0.94	1.96		0.65
					4.28			2.99	
4	5.72	729	2.57	7.09		1.77	4.95		1.24
					9.25			5.01	
5	7.20	828	4.07	16.34		3.27	9.96		1.99
					8.73			4.33	
6	9.21	949	6.66	25.07		4.18	14.29		2.38

* Plantation established in 1975 at 3.0m x 3.0m spacing.

** Volume of stem stump to tip, including bark (m^3).

*** Weight (oven-dry tonnes) of whole tree excluding leaves (0.5 ODT = 1.0 green tonne).

Table 8-11

Growth and yield comparison of Codrington and Domtar sites after six years for clone '1-45/51'

	Location		Difference between sites		Difference due to				
					Site		Spacing		
Parameter	Codrington	Domtar I	%	cm	% of Total	cm	% of Total	cm	% of Domtar I
Total Height (cm)	1090	874	24.7	216	100	216	N/A	N/A	N/A
Diameter (cm)	13.71	8.61	59.23	5.10	79.4	4.05	20.6	1.05	12.2

Table 8-12

Growth and yield projection and comparisons between different densities for six-year-old '1-45/51' at Domtar I

Spacing	Growing area/tree (m^2)	Stems /ha	Average height (cm)	Average diameter (cm)	Volume /ha (m^3)	Biomass /ha (ODT)
3.6 m x 3.6 m	10.0	1000	874	8.61	22.92	11.16
3.0 m x 3.0 m	13.0	760	874	9.74	21.68	10.23

Figure 8-7

Cumulative diameter growth
for '1-45/51' over six years

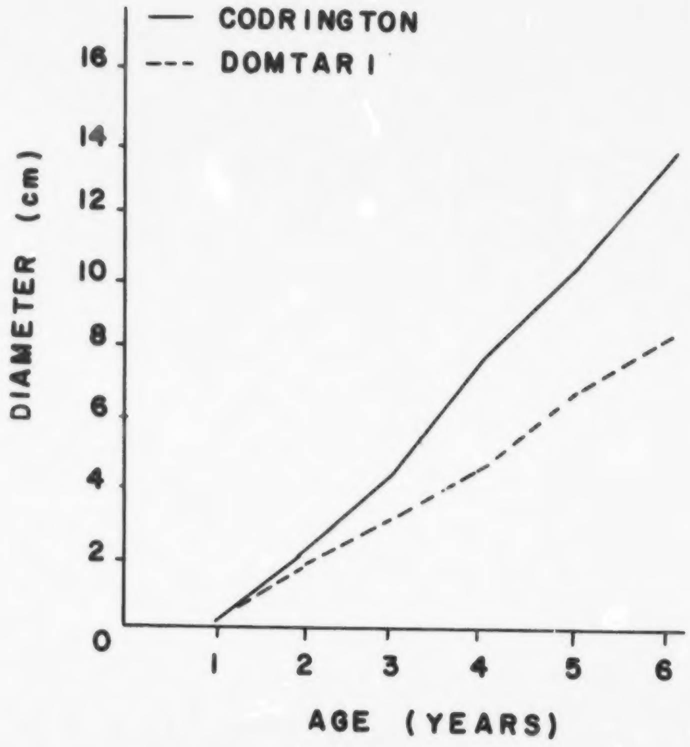


Figure 8-8

Cumulative volume increment
for '1-45/51' over six years

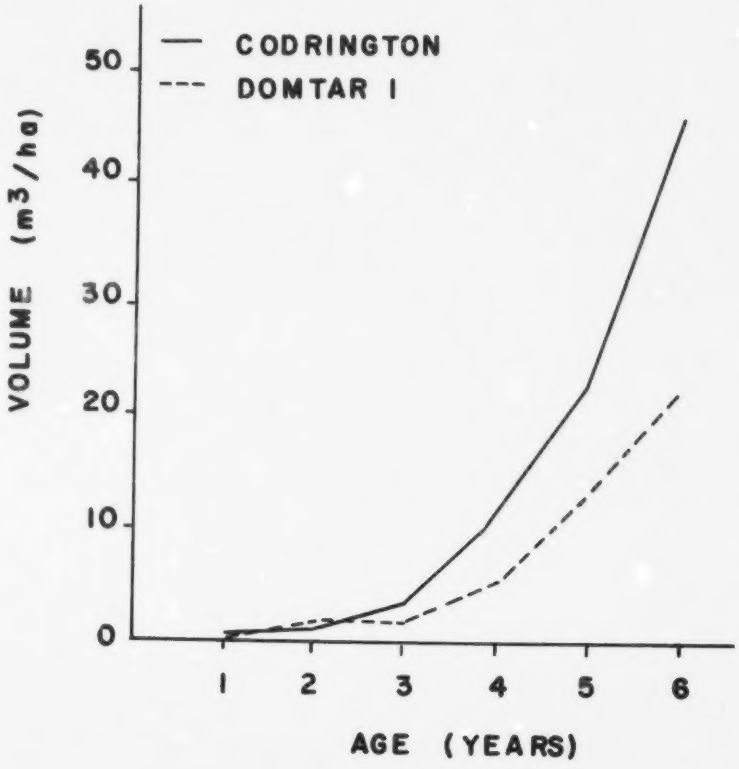


Figure 8-9

Cumulative height growth
for '1-45/51' over six years

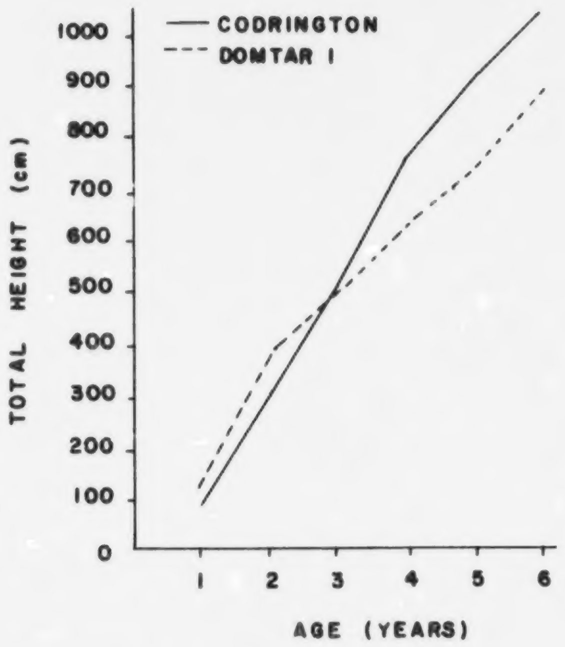
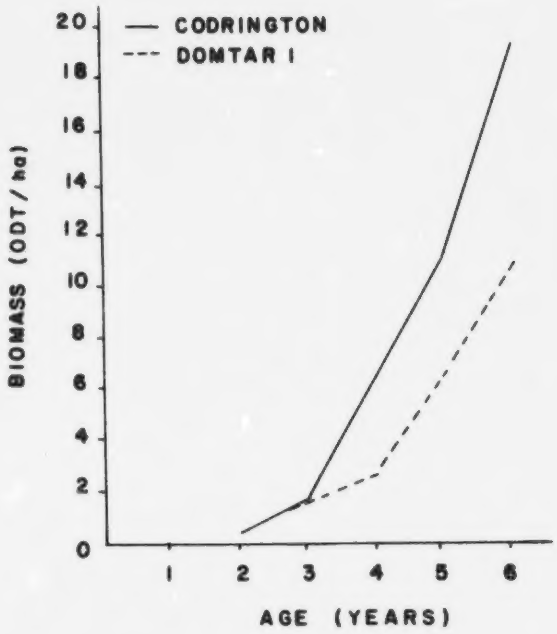


Figure 8-10

Cumulative biomass increment
for '1-45/51' over six years



results from spacing differences. The 1.05 cm of diameter increment equates to 12.2 per cent in diameter. This percentage value is somewhat conservative in view of the 27 per cent increase in diameter cited by Krinard (1975).

Table 8-12 (see page 226) projects growth and yield for clone 'I-45/51' at the Domtar 1 site.

Based on an increase of 12.2 per cent in diameter and on no increase in height due to increased spacing, the average diameter for each diameter class in year six was increased and the frequency distribution adjusted to 760 trees per hectare. Volume and biomass yields were derived using volume and biomass equations presented in Table 8-6.

Volume and biomass yields between the two systems are not significantly different. With increasing age, the yield of a 3.6 m x 3.6 m plantation should surpass that of a 3.0 m x 3.0 m plantation, as indicated in the yield increment trends in Figures 8-8 and 8-10.

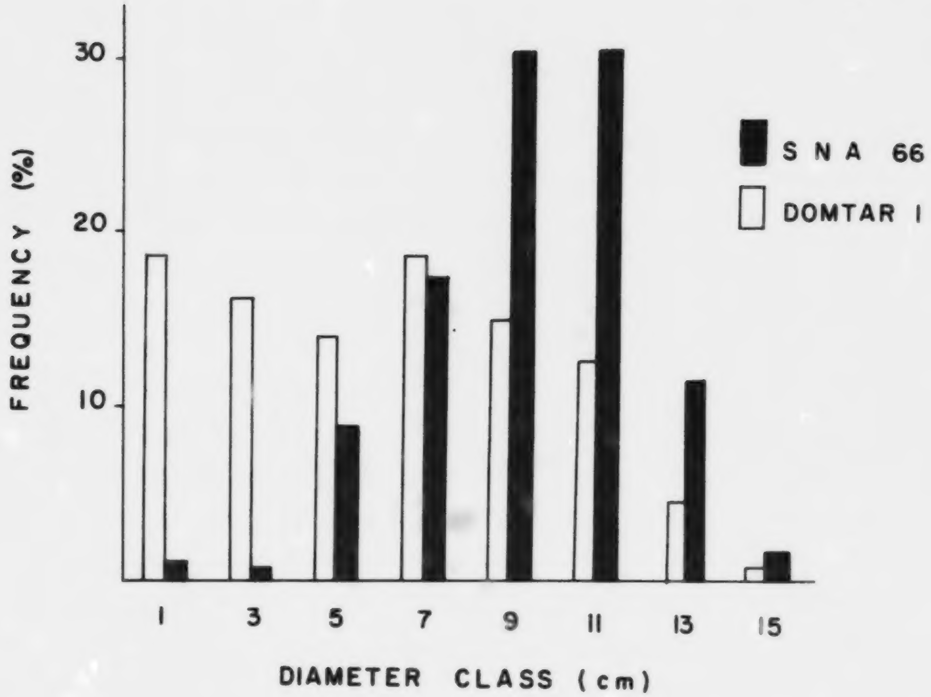
The benefits of employing a 3.6 m x 3.6 m versus 3.0 m x 3.0 m spacing are: lower establishment costs (planting, weed control); production of equal or greater volume per unit area; production of larger trees which will lower harvesting costs; and larger wood fibre yields (i.e., larger bole wood:bark ratio).

Performance of Refills

Figure 8-11 gives the frequency distribution of diameters classes for clone 'DN 17' growing at SNA 66 and Domtar 1. The diameter distribution for the SNA 66 plantation is similar to the distribution normally observed for an even-aged stand. The diameter distribution for Domtar 1 shows a large deviation from

Figure 8-11

Comparison of 1980 diameter class frequency for clone 'DN 17' at SNA and Domtar I



the expected or normal even-age distribution. This is due to several factors:

1. Poor initial planting success, resulting in refill operations in the second year. Refill performance is usually poor and variable.
2. Varying weed control success in the establishment years, causing variation in growth within the plantation.
3. Microsite effects (variation in clonal response to site variation).

The Quality and Quantity of Coppice Regeneration

The quality and intensity of management in the first rotation has a pronounced influence on subsequent rotation yields as does the quality of harvesting. Two features of coppice regeneration, quantity and length, will be discussed. No data is presently available for Ontario stands.

Various studies on poplar coppice systems have cited increased yields per unit area after the first harvest. De Bell (1975) reported a 117 per cent increase in yield (ODT/ha/yr) in the second rotation of a system 27K Populus trichocarpa Hook (Black cottonwood) plantation and a 200 per cent increase for a system 6.8K plantation. Table 8-13 shows the increase in yields reported by Heilman et al. (1972) in the second rotation of a P. trichocarpa plantation.

Table 8-14 shows the productivity growth data from coppice versus single stem growth for two P. trichocarpa plantations on the same site in British Columbia as given by Smith, (1980).

Although the individual stems were smaller for the coppice plantation, there was 18.6 per cent greater

Table 8-13

Yield (ODT/ha/year) at three different spacings

Spacing	0.3 m x 0.3 m	0.61 m x 0.61 m	1.22 m x 1.22 m
Stems/ha	111,111	27,777	6,700
Yield (ODT/ha/yr)			
First rotation	6.76	4.80	2.34
Second rotation	9.10	11.62	8.09
% increase in yield	34.60	142.00	246.00

After Heilman et al., 1972

Table 8-14

Yield (m^3) of coppice versus single stem growth

	Age (years)	Stems per ha	Ave. Dia- meter (cm)	Ave. Ht. (m)	Volume per ha (m^3)	MAI (m^3)	Differ- ence in MAI (%)
Single Stem	20	247	31.2	29.0	258	12.9	18.6
Coppice Growth	21	420	26.4	29.8	322	15.3	

After Smith, 1980

volume increment per hectare due to the larger number of stems. The question of how many rotations are biologically possible for each management system has still to be answered in eastern Ontario.

Several factors must be considered when evaluating the need to replace the root systems in a plantation area.

Lack of coppice vigour after several harvest periods may result in a decline in both the number of stems per stool and the average height and diameter of stems. The rate of mortality may increase within a stand and insect and disease problems may become more evident. As technology develops in eastern Ontario, improved culture should lead to greater coppice yields after the first harvest.

9 THE PRODUCER

Future reforestation efforts in southern Ontario will be largely governed by the amount of timber that can be grown on private land. Before the private sector becomes involved in the establishment of hybrid poplar plantations in a substantial way, the economic feasibility of this investment opportunity will need to be demonstrated. This chapter presents a framework for analyzing the financial implications of hybrid poplar production and is oriented specifically towards the private entrepreneur, i.e., the farmer or corporation.

This chapter discusses the first attempt to develop a computer model to analyze and evaluate the entire range of input costs experienced in establishing hybrid poplar plantations. It also analyzes cost data derived from the hybrid poplar program. Some of the data will require further

further refinement with time and should be viewed accordingly.

The following will be presented here:

- An outline and description of the major factors to be considered in making an investment decision.
- The current value of input costs such as land values, site preparation, planting and stock costs.
- A computer model to calculate the internal rate of return, contingent upon defined input costs and acceptable stumpage prices.
- A range of scenarios based on various assumptions about the factors affecting hybrid poplar development.
- A sensitivity analysis of factors to determine their significance.

The major result of the model is the identification of the most important factors affecting the economics of producing hybrid poplar.

Key Development Factors

Six factors are addressed in this analysis of the economics of hybrid poplar production:

- Management systems
- Input costs
- Land
- Harvests
- Yield
- Stumpage prices

Some of these factors, such as yield and land, are asociated with a range of values.

Management Systems

The Ministry uses three management systems for the growing of hybrid poplar. Each is characterized by the number of trees planted per hectare and the interval between subsequent harvests on the same root system (Table 9-1).

Input Costs

Costs vary with each system; various inputs with their associated costs are listed in Table 9-2. All costs are expressed in 1980 dollars. A more detailed breakdown of the component costs is given in Appendix 6. Appendix 7 lists comparative costs for the various operations based on a survey of agricultural costs in Ontario; this information has been used in additional runs of the model. It is assumed that land may be leased, bought or already in the possession of the entrepreneur. A different input cost is associated with each of these options.

The land leasing costs used are based on an estimated value of marginal agricultural land in eastern Ontario and current leasing rates. Land values range from $500 to $1,400 per hectare. An average of $750 per hectare is assumed for this analysis. Leasing rates vary between five and 10 per cent of the value of the land. Therefore, assuming a leasing rate of seven per cent of the land value, a leasing rate of $52.50 is used. The leasing rate includes taxes and administration costs.

Under the assumption that the land is already owned, land would have been purchased for other reasons, such as agriculture or recreation, and the unused

Table 9-1

Characteristics of hybrid poplar management systems in eastern Ontario

Characteristic	System 35K High Density	System 4K Medium Density	System 1K Low Density
Number of trees per hectare	35,000	4,000	1,000
Number of years interval between harvests	2	5	10

Table 9-2

Costs for various operations

Operation	Management System 35K	4K	1K
Site preparation (Year 0)	458.75	458.75	458.75
Planting (Year 1)	2,020.00	175.00	62.50
Stock (Year 1)	937.50	100.00	25.00
Weed control			
Year 2	-	275.00	275.00
Year 4	212.50	-	-
Fertilizer (Alternate years)	92.50	not supplied	not supplied

All values are in 1980 dollars.

portion would have no production value or opportunity cost unless used for hybrid poplar. It has been assigned a value of $0.00 per hectare. Land may be bought specifically for hybrid poplar production. In this case all land costs are assumed to be recoverable at the end of the operation and hence have been assigned a cost of $0.00 per hectare.

Harvests

At the present time, it is unknown how often regeneration will occur from the same root system. It is anticipated that a range of three to five harvests is possible depending on the site and the management system. In order to cover the extreme cases, a range of two to 14 harvests was examined in the model.

The Model

The central focus of this chapter is a computer model that generates an internal rate of return (IRR) for each management system by applying values to the factors that have been listed. The IRR is the rate of discount that will equate the present value of the net benefits with the present value of the cost of a project. In other words the IRR is the rate of return or the yield on an investment.

The potential investor in hybrid poplar development will estabish his minimum IRR at the level necessary for his perception of a project's risk and the value of his capital. This value is determined by the cost of borrowing capital and possible returns from alternative ventures.

Currently (July, 1981), a risk-free investment in Canada, such as bank savings certificates, yields 16 per cent with inflation at a level of 12 per cent. Under these circumstances, potential investors in a project will want an IRR for the project greater than 16 per cent to compensate for the project's perceived risk.

A changing value for the dollar makes it difficult to compare various investment scenarios over varying lenths of time. For example, if 12 per cent inflation is assumed, $100 in 1980 is equivalent to $310.58 in 1990 dollars. All costs in this paper are in constant 1980 dollars, thereby eliminating inflation from the calculations. In an inflation-free environment an investor would expect an IRR from a risk-free project of at least four per cent. The importance placed on risk will vary according to each project. Hence, the acceptable IRR will increase according to the degree of risk. For example, hay production in Ontario has an expected IRR of five per cent (OMAF to 1979).

The model contains variables for input costs, land costs, stumpage price, yield and number of harvests. Mathematically expressed, it is as follows:

$$\sum_{0}^{n} \frac{R - C}{(1 + r)^{n}} = 0$$

Where: R = revenues (volume x stumpage)
C = all input costs
r = internal rate of return
n = number of years

The revenues represent the stumpage value of all ODT's harvested. The model calculates all costs and revenues in constant 1980 dollars and the internal rate of return is the real rate above inflation. In addition, the model describes the importance or significance of the various input factors for each scenario as the percentage each variable represents of the total costs.

Base Case

In the description of the key development factors, a range of values for each was outlined. These ranges were necessary because of the preliminary nature of the data and the inherent variability involved in establishing plantations.

A base case was developed using a "reasonable" value for each of the variables. This base case is not introduced as the suggested best solution, but merely as a referance point to which other cases can be compared. Values used in the base case can be changed and incorporated into the model. In later runs of the model, changes to these values are introduced, and the effect and importance of such changes are highlighted. Table 9-3 lists the values applied to each of the factors in the base case.

Table 9-3

Base case values

	Management System			
Operation	35K	4K	1K	
Site preparation	458.75	458.75	458.75	0
Planting	2,020.00	175.00	62.50	1
Stock	937.50	100.00	25.00	1
Weed control				
Year 2	-	275.00	275.00	2
Year 4	212.50	-	-	4
Fertilizer	92.50	not used	not used	alternate years
Land (per year)				
Free	0.00	0.00	0.00	all years
Rent	52.50	52.50	52.50	all years
Yield per harvest	45 ODT	45 ODT	45 ODT	n/a
Harvests	5	5	5	n/a
Stumpage price	$8/ODT	$8/ODT	$8/ODT	n/a

1980 dollars

n/a = not applicable

Base Case Results

By using the base conditions (Table 9-3), an investor can expect an annual IRR ranging from -203.89 per cent to 4.52 per cent depending on the management system or the land cost assumption. The result for 4K system (land free) is the most attractive at 4.52 per cent annual IRR over five harvests, which for this system spans some 26 years. In other words, an investor receiving this return has has made 0.52 per cent over a risk-free investment such as Canada Savings Bonds. An investor in short rotation (land free) with an annual (land free) with an annual return of 3.03 per cent would make almost one percentage less in this option than with Canada Savings Bonds. The full results are presented in Table 9-4, using the values for costs given in Table 9-3.

Table 9-4

Internal rate of return for base case levels

	IRR - Base Case ($)		
	35K	4K	1K
Land free	-13.28	4.52	3.03
Land rent	-18.22	-3.85	-203.89

All values are per cent IRR.

All the land rent options incur costs greater than expected revenues and therefore have negative IRR's. Similarly, 35K (land free) management systems have greater costs than revenues. Only the 4K and 1K (land free) systems have a positive balance of costs and revenues. However, the 51-year duration of the 1K system makes it slightly less attractive than the 4K system.

In interpreting these results, a note of caution should be made. Stumpage rates are in 1980 dollars, for which the base case rate is $8/ODT. By introducing the effects of inflation, the current value (or the value projected at the end of the relevant period) changes drastically. Table 9-5 shows the corresponding stumpage rate at current value, after five harvests.

Variable Significance in Base Case

The impact of the various factors on the total costs of the base case were analyzed to identify the extent of their influence. The most important variables for each management system are summarized in Table 9-6.

The costs associated with 35K are greatly influenced by planting and stock costs. Costs for 4K and 1K are affected mainly by site preparation and weed control costs. Under the land rented options, land costs which accumulate over 26 and 51 years, respectively, dominate these latter two systems.

The relative importance of each cost factor is summarized in Figures 9-1 to 9-6 which demonstrate the changing importance of the respective input costs as the number of harvests are varied.

Other Cases

Two additional cases to the base case are examined in detail and analyzed. The first incorporates the assistance offered under the Ontario Woodlands Improvement Act; the second examines the effect of including a free stock option in the base case.

Table 9-5

Projected stumpage prices at the fifth harvest of each management system

Year of Harvest Number 5	Management System	Inflation Rate	Stumpage Price
1980	Present	12%	8.00/ODT
1992	35K	12%	37.17/ODT
2006	4K	12%	152.32/ODT
2031	1K	12%	2,589.46/ODT

Table 9-6

Variable significance in base case

Management System	Land Cost Assumption	Factor	Significance or % Total Cost
35K	Free	Planting Cost	52%
		Stock Cost	24%
	Rented	Planting Cost	45%
		Stock Cost	21%
4K	Free	Site Preparation	47%
		Weed Control	26%
	Rented	Land	47%
		Site Preparation	25%
1K	Free	Site Preparation	57%
		Weed Control	32%
	Rented	Land	60%
		Site Preparation	23%

Figure 9-1

Significance of input costs for System 35K
assuming land rent, for varying number of harvests

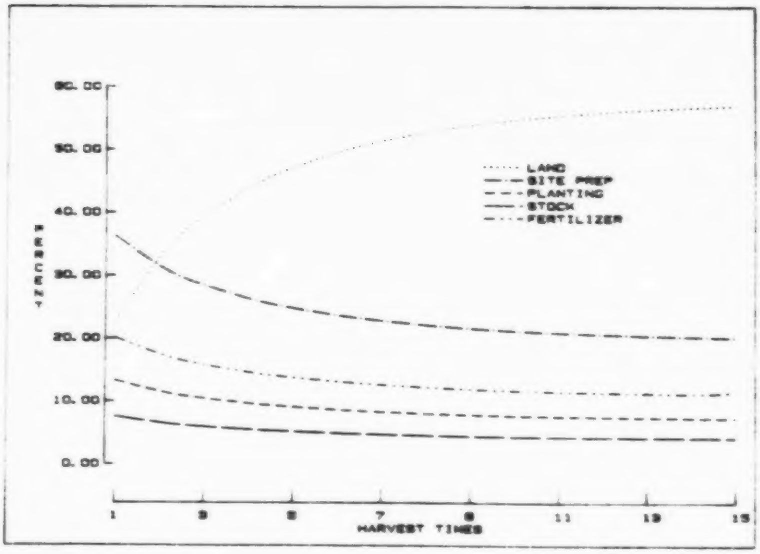


Figure 9-2

Significance of input costs for System 4K
assuming land rent, for varying number of harvests

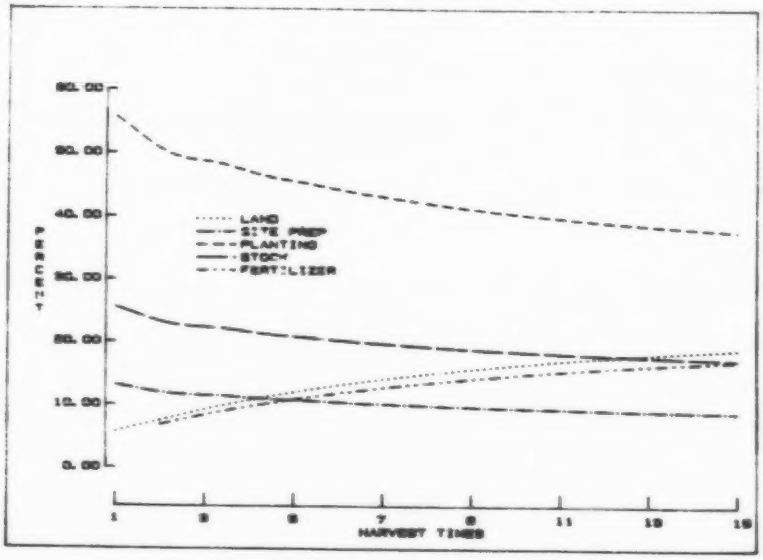


Figure 9-3

Significance of input costs for System 1K assuming land rent, for varying number of harvests

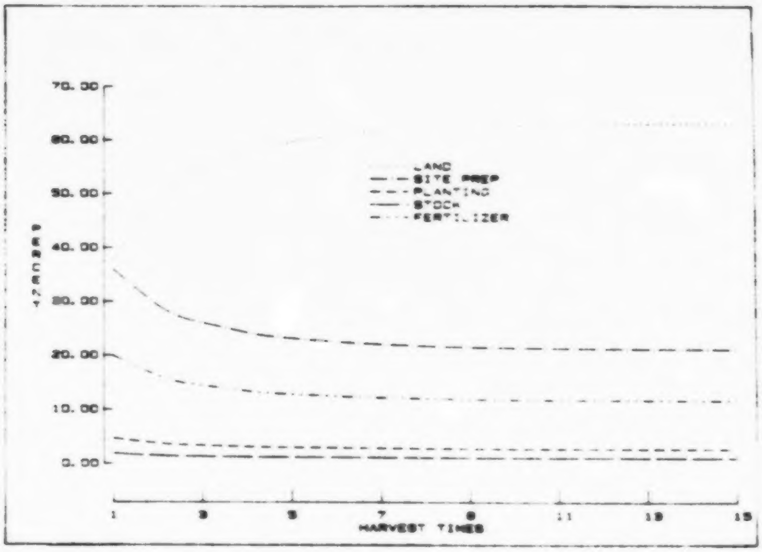


Figure 9-4

Significance of input costs for System 35K assuming land free, for varying number of harvests

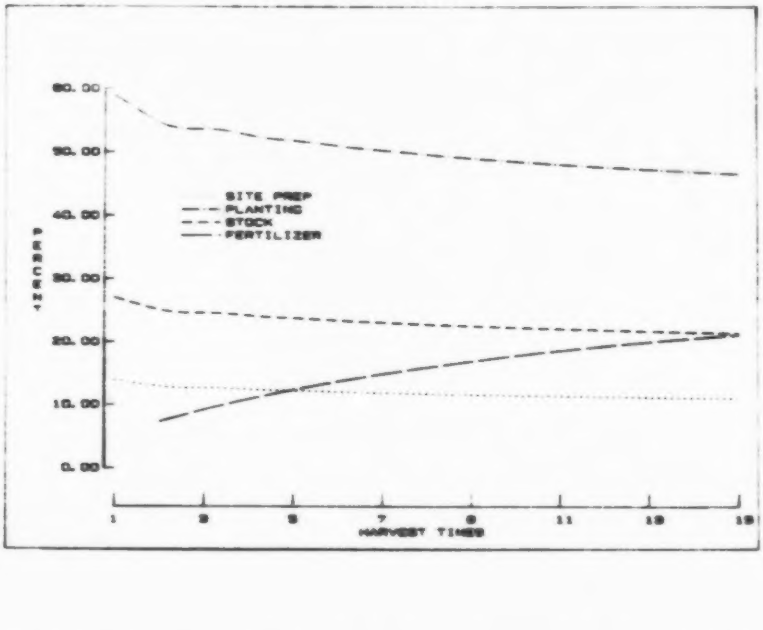


Figure 9-5

Significance of input costs for System 4K assuming land free, for varying number of harvests

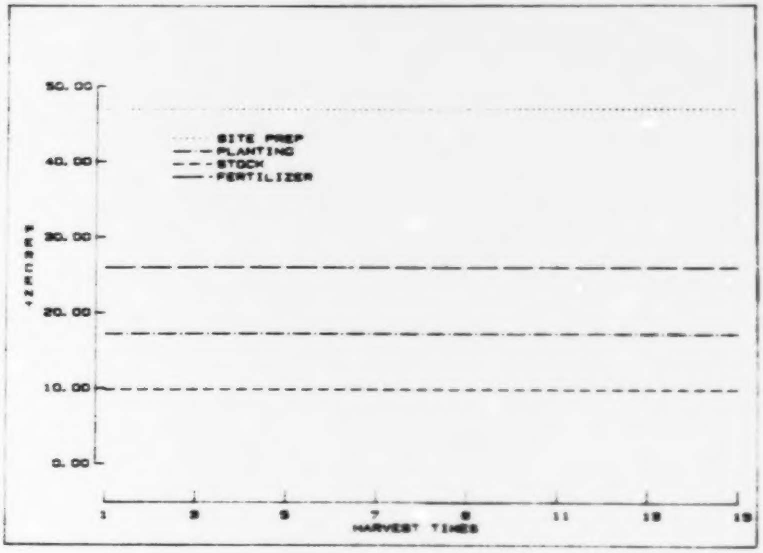
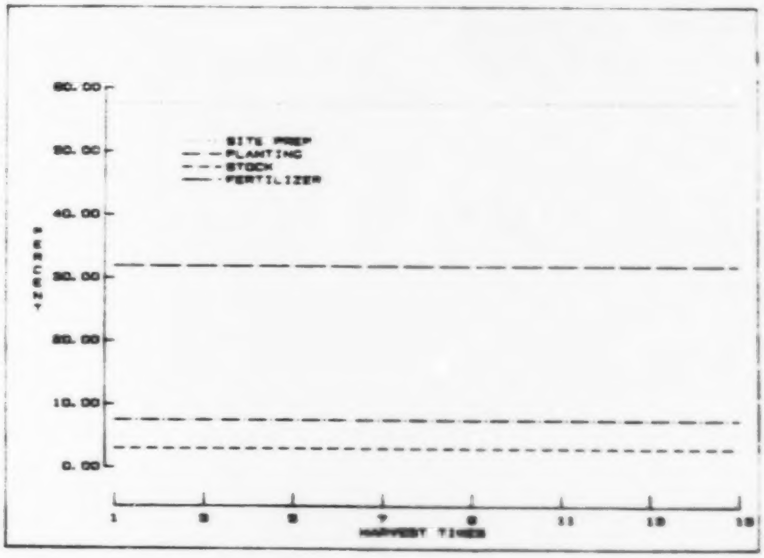


Figure 9-6

Significance of input costs for System 1K assuming land free, for varying number of harvests



Woodlands Improvement Act (WIA)

The Woodlands Improvement Act offers financial assistance to landowners who either rehabilitate their woodlands or reforest their land (it is assumed the WIA Agreement would cover all relevant costs, i.e., up to 51 years for short rotation). In return for a 15-year commitment by the owner to have his woodland properly managed, the Ministry of Natural Resources will undertake site preparation, planting and all fertilizer and weed control applications, or reimburse the owner for doing the same. The owner agrees to pay for planting stock and provide protection. Since the Ministry assumes the majority of costs, the resulting IRR increases dramatically, making each of the management systems attractive particularly when land is assumed to be free (Table 9-7). Again the 4K system is revealed as the most attractive investment.

Table 9-7

Internal Rate of Return (IRR)
for base case under WIA

	35K	4K	1K
Land free	12.77	43.95	35.26
Land rent	3.52	5.95	n/a*

All values are per cent IRR.

* The IRR is either extremely low or could not be generated by the computer in less than 30 iterations. In such cases the results are deemed to be too low to consider.

When the land is considered free, for all three systems the stock represents 100 per cent of the landowners cost. When land rent is included, stock costs represent 82 per cent of the costs in the 35K system, and for the 1K and 4K systems stock costs represent only four to 15 per cent of the total costs (Table 9-8). The impact of varying the stumpage rate was examined for the same base case under WIA. Figures 9-7 and 9-8 illustrate the impact of increased stumpage prices on the IRR of all three systems. Figure 9-8 indicates that beyond a $10 stumpage rate in the land rate in the land rent option, the 35K and 4K rotations show a rapid increase in their IRR, particularly when compared to 1K.

Table 9-8

Factor significance in the base case under WIA

	35K	4K	1K
Land free	Stock 100	Stock 100	Stock 100
Land rent	Stock 82	Land 85	Land 96

Values represent per cent of the total cost represented by the major cost factor.

Free Stock Option

In certain other jurisdictions government or private industry may offer free planting stock to woodland owners as an inducement to put their land into forest production. As Table 9-9 indicates, such an option has a significant impact on IRR only on the 35K system which is still financially unattractive at a stumpage price of $8/ODT.

Table 9-9

IRR for base case with free stock option

	35K	4K	1K
Land free	-9.52	5.43	3.6
Land rent	-15.14	-3.37	-203.72

All values are per cent IRR.

Figures 9-9 and 9-10 show the impact of free stock on the IRR of the three systems as the stumpage price is

Figure 9-7

IRR for systems 35K, 4K and 1K under WIA, assuming land free, for varying stumpage prices

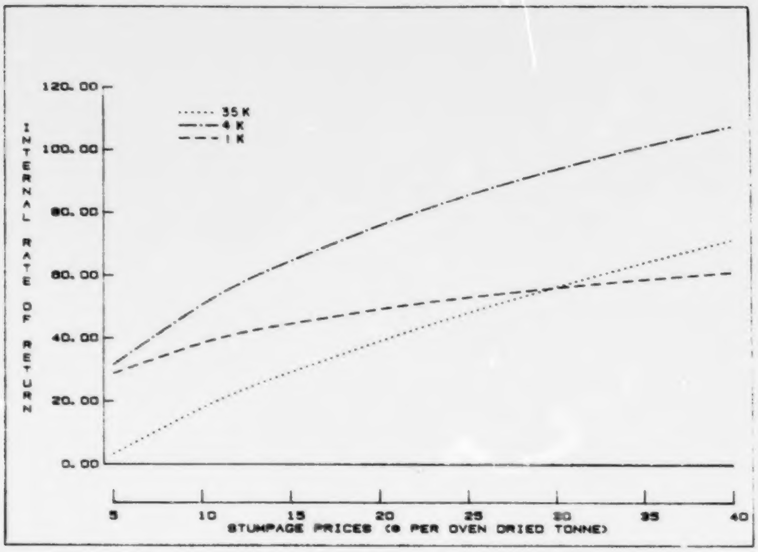


Figure 9-8

IRR for systems 35K, 4K and 1K under WIA, assuming land rent, for varying stumpage prices

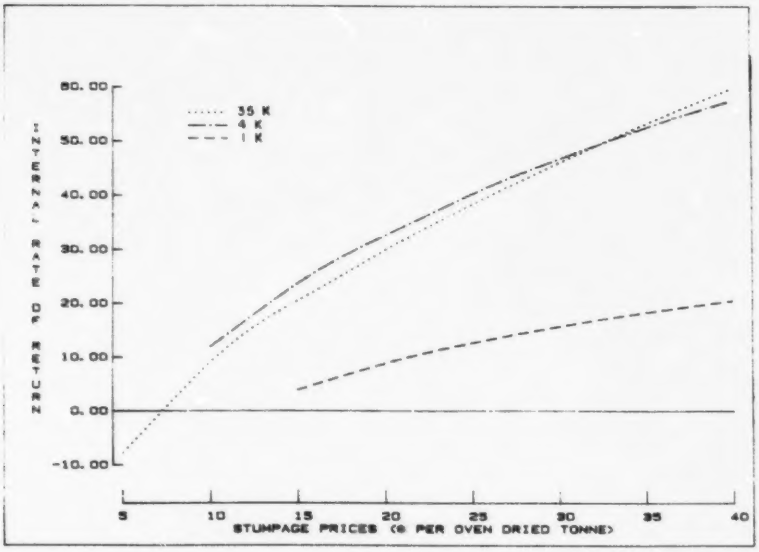


Figure 9-9

IRR for systems 35K, 4K and 1K with free stock option, assuming land free for varying stumpage prices

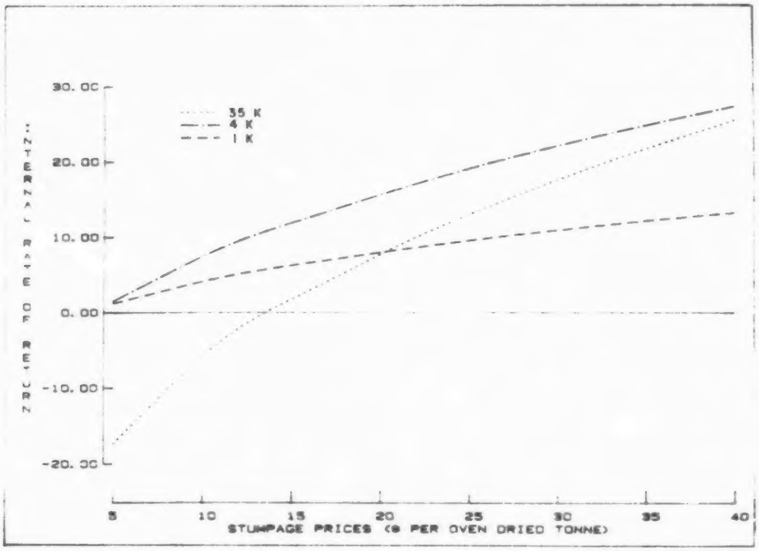
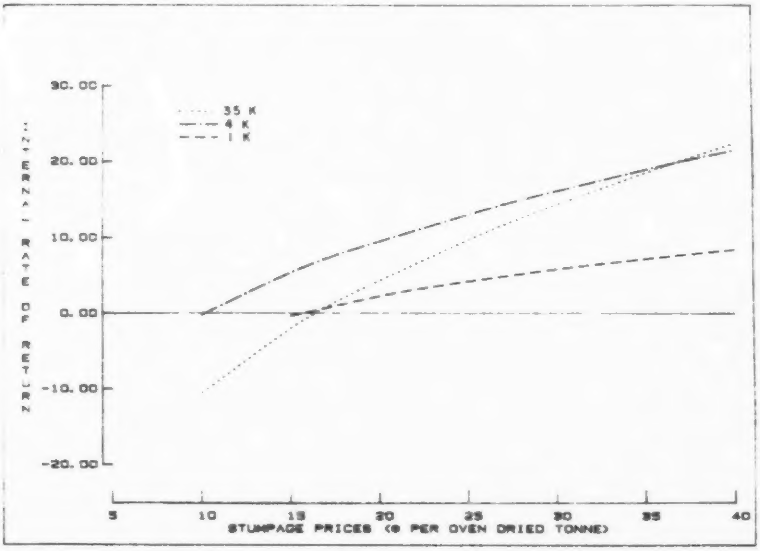


Figure 9-10

IRR for systems 35K, 4K and 1K with free stock option, assuming land rent for varying stumpage prices



increased. The rates of increase in IRR for the 35K and 4K rotations are greater than for the 1K rotation whether land is free or rented.

Additional Scenarios

The previous two cases addressed the input costs associated with the base case. The WIA option included subsidies on most input costs whereas the second case eliminated the stock costs. However, there will be many variations from the base case, as was indicated in the description of the range of values that could be applied to the key development factors. For example, the following variables can change:

- Number of harvests
- Average annual yield
- Agricultural scale preparation costs
- Stumpage prices

The following sections outline some changes to the base case and the resultant effects on the IRR.

Ten harvests (rather than five as in the base case)

In this situation the IRR is increased marginally with each additional harvest (Table 9-10). The greatest increase is for the IRR from the 35K system, however it still remains negative. The 4K system's IRR increases from 4.5 per cent to 6.3 per cent.

Table 9-10

IRR for base case with number of harvests increased from five to 10

	35K	4K	1K
Land free	-2.33	6.30	3.71
Land rent	-6.07	-0.26	n/a*

All values are per cent IRR.

* The IRR is either extremely low or could not be generated by the computer in less than 30 iterations. In such cases the results are deemed to be too low to consider.

Two Harvests

In order to test the effect on the IRR of reducing the number of harvests, a two harvest scenario was examined. Under this scenario the IRR drops precipitously, particulary in the 35K, land rent option (Table 9-11). The least effect is with the 1K rotation (land free).

Table 9-11

IRR for base case with number of harvests decreased from five to two

	35K	4K	1K
Land free	-174.03	-4.82	-0.91
Land rent	-684.68	-15.02	n/a*

All values are per cent IRR.

* The IRR is either extremely low or could not be generated by the computer in less than 30 iterations. In such cases the results are deemed to be too low to consider.

It is re-emphasized that the above results are based on a stumpage price expressed in constant 1980 dollars. The IRR associated with each successive harvest from the second to the fourteenth are shown in Figures 9-11 and 9-12.

Figure 9-11

IRR for systems 35K, 4K and 1K assuming land free
for varying number of harvests

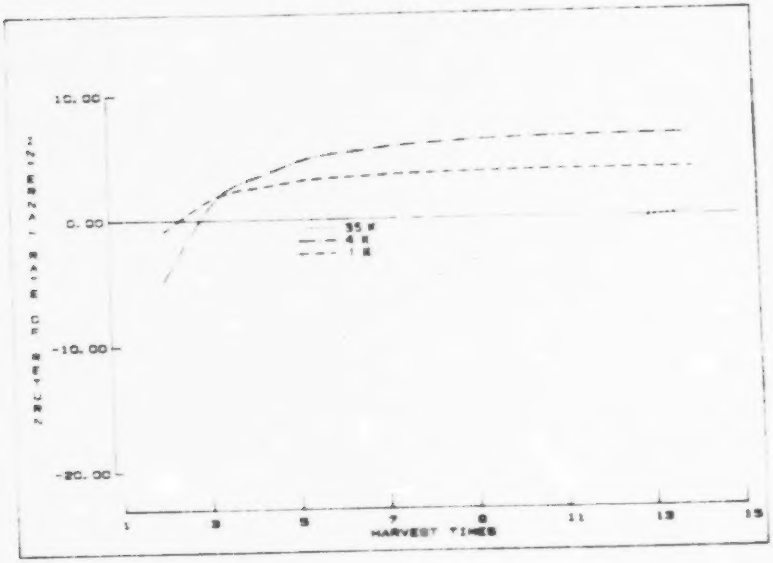
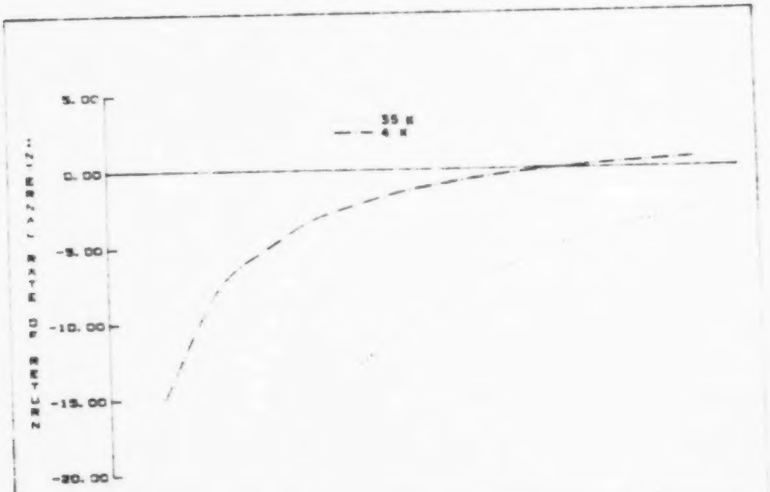


Figure 9-12

IRR for systems 35K and 4K assuming land rent
for varying number of harvests



Changes in Yield

The base case assumed 45 ODT/hectare per harvest. Should this be increased to 75 ODT/hectare, the resulting effect on stumpage rate is given in Table 9-12.

Table 9-12

IRR for base case with yield increase from 45 ODT to 75 ODT per harvest

	35K	4K	1K
Land free	-5.05	9.47	5.50
Land rent	-8.49	-3.11	-1.51

All values are per cent IRR.

The IRR increases substantially across all systems. System 4K (land free) remains the most attractive while 1K (land free) approaches attractiveness.

Figures 9-13 and 9-14 outline, for each system, the possible increase in IRR as yield per hectare changes. It should be noted that the results are based on the assumption that five harvests will be made.

Agricultural Scale Preparation Costs

In the base case, MNR's field preparation costs were used. This type of operation has typically occurred on a smaller scale than is generally experienced with agricultural operations. In view of this, costs which were collected for equivalent agricultural preparations (Appendix 6) (23 per cent less than MNR costs) were

Figure 9-13

IRR for systems 35K, 4K and 1K assuming land free
for varying yields at harvests

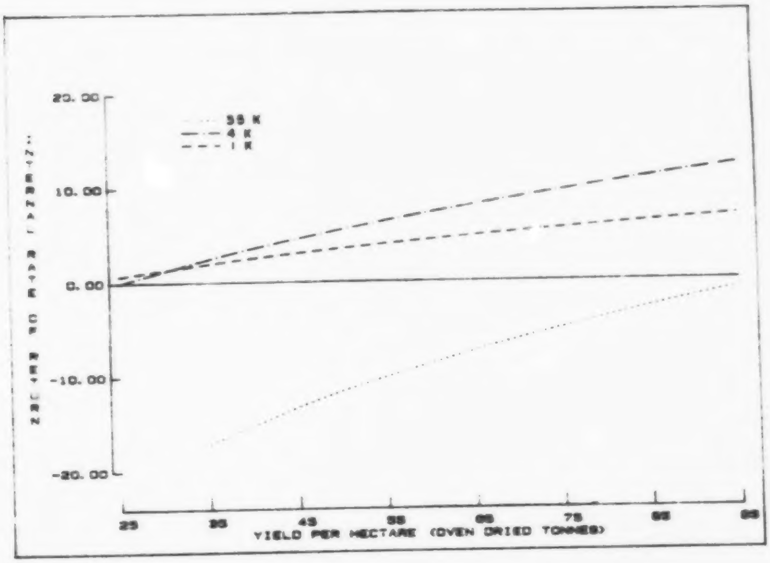
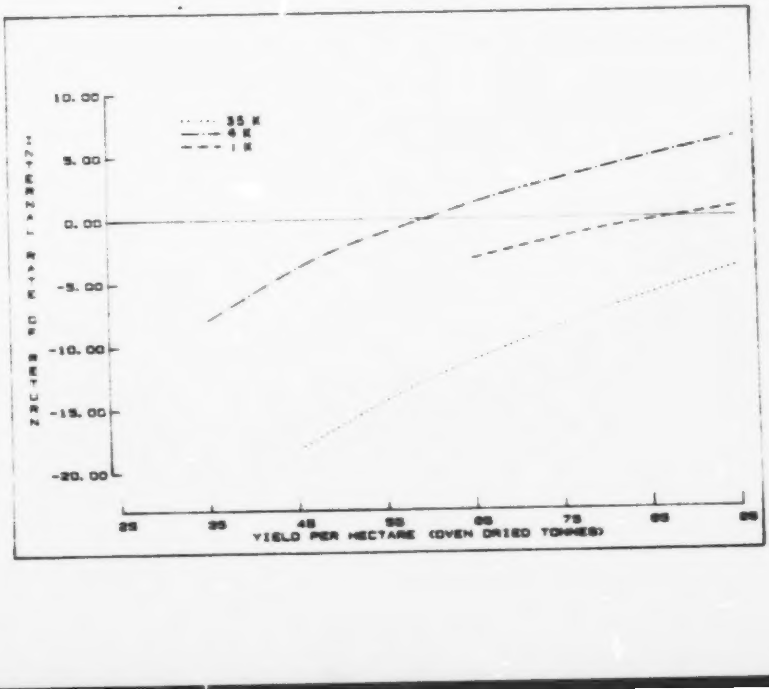


Figure 9-14

IRR for systems 35K and 4K and 1K assuming land rent
for varying yields at harvests



tested, and resulted in a modest increase in the IRR (Table 9-13).

Table 9-13

IRR for base case using agricultural scale input costs

	35K	4K	1K
Land free	-12.96	5.58	3.69
Land rent	-17.97	-3.34	n/a*

All values are per cent IRR.

* The IRR is either extremely low or could not be generated by the computer in less than 30 iterations. In such cases the results are deemed to be too low to consider.

Variable Stumpage Price

The IRR of all three systems in the base case increases as the stumpage price is increased. The 35K system increases at the greatest rate. However, because this system begins at such a large negative IRR, it does not become financially attractive until the stumpage price reaches $30/ODT. The 1K system is least sensitive to changes in the stumpage rate. With the 4K system, the IRR does not increase as quickly as the IRR of the 35K system. However, it starts at a higher level and remains the most attractive financial proposition. The 4K system's IRR approximately doubles as the stumpage price doubles (Figures 9-15 and 9-16).

Further Cases

The number of variations that could be examined are infinite. However, four additional options are included in Table 9-14 for comparison with the base case. These indicate some of the impacts on the IRR that can be

Figure 9-15

IRR for systems 35K, 4K and 1K assuming land free for varying stumpage prices

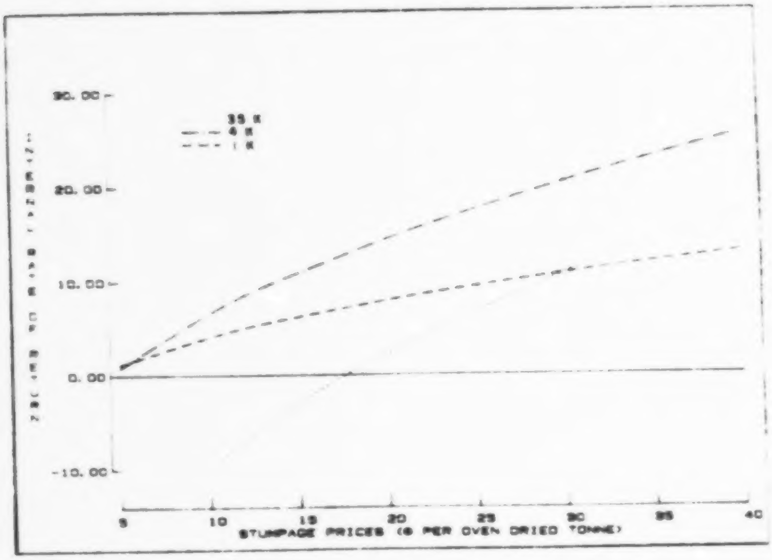


Figure 9-16

IRR for systems 35K, 4K and 1K assuming land rent for varying stumpage prices

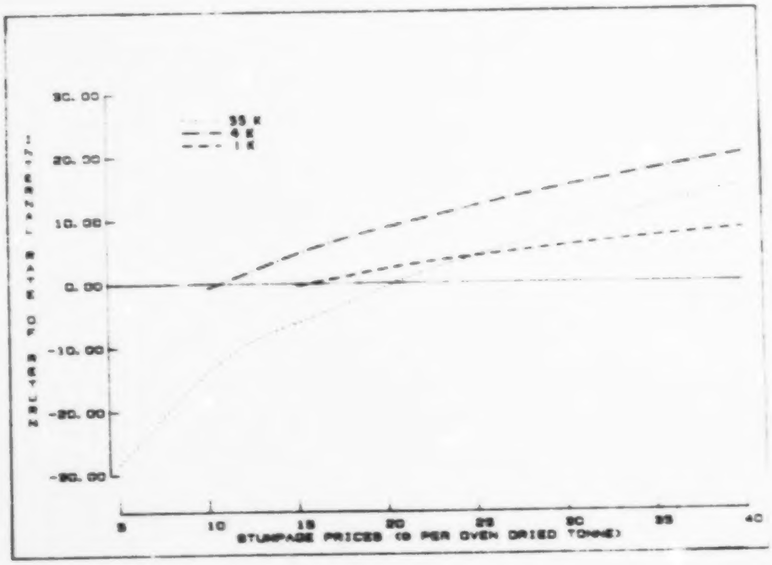


Table 9-14

Sensitivity of the IRR to changes in base variables

Change to base case		Impact on IRR relative to base case 35K	4K	1K
Land lease rate increased from 7% to 10%	Land Free	0	0	0
	Land Rent	-1.5	-5	n/a**
Herbicide and fertilizer costs reduced by 20%	Land Free	0.84	0.72	0.45
	Land Rent	0.96	0.37	0.6
Planting costs reduced by 20%	Land Free	1.46	0.3	0.06
	Land Rent	1.21	0.16	0.09
Additional input cost of $10/hectare for crop insurance in WIA case*	Land Free	-1.81	-11.35	-17.56
	Land Rent	-3.91	-10.43	n/a**

All values represent the change in IRR relative

* Relative to the base case under WIA.

** The IRR is either extremely low or could not be generated by the computer in less than 30 iterations. In such cases the results are deemed to be too low to consider.

anticipated with significant changes in technology. For example, an additional annual cost of $10 per hectare has a significant negative impact on the IRR realized under WIA. Such analysis can prove useful in making management decisions, such as assessing the benefit of crop insurance.

Other Issues

In addition to the factors that were examined in the above scenarios, there are other economic considerations that the potential investor will take into account. The two major aspects will be transportation costs and harvesting costs.

The buyer of wood fibre will consider transportation costs in terms of the stumpage price he is prepared to pay. A source of poplar within 40 km of the plant will become an increasingly attractive proposition in view of the expected escalation in the transportation costs. Therefore, transportation cost is a factor to be built into the financial feasibility of poplar production. For example, the 1981 cost difference between transporting wood 32 km and 128 km is $8.05/ODT (Peat Marwick and Partners, 1981).

This difference in transportation costs is already partially recognized in the difference in stumpage price paid by contractors. In 1980, contractors paid between $10 and $11/ODT for wood 32 km away from its destination, compared to $7 to $8/ODT for wood 128 km away. On average, the more distant wood has a lesser stumpage price by $3.30/ODT but a greater transportation cost by $8.05/ODT. Therefore, the more distant wood costs $4.75/ODT more. A potential purchaser of wood on the stump would be willing to pay a premium for wood closer to its ultimate destination. This would be equivalent to the transportation and stumpage cost difference.

Differences in harvesting costs of naturally grown mixed hardwoods and plantation grown hybrid poplar have been compared (Peat Marwick and Partners, 1981). It was estimated that for plantation grown hybrid poplar, harvesting costs were $17.75/ODT, which is $5/ODT less than the harvesting cost of mixed hardwoods at $22.85/ODT. Again, a potential purchaser would be willing to pay part of this difference, in the form of a higher stumpage price, for access to the more economically harvested hybrid poplar. Depending on the distance of a hybrid poplar plantation from a mill and the savings associated with harvesting such a plantation, stumpage prices could be raised between $4 and $10/ODT (1980 dollars).

Property and income tax implications for the investor are also important. These will vary in importance depending on the owner. They will also vary according to the program subsidy the entrepreneur could receive. This could be an additional factor to be introduced to the model, but for present purposes it was considered too specific to individual investor needs to be included in the general approach adopted here.

Conclusion

Throughout the analysis, a number of significant factors have become evident and major trends have emerged. Of the three management systems analyzed, 4K (land free) showed the greatest potential for profitability generating the highest internal rate of return (IRR), surpassing both the 35K and 1K rotations. The 1K management system generally exhibited a relatively poor

IRR because of its relatively longer rotation. This was particularly evident with the inclusion of the land rent option. In the case of the 35K system the low IRR was due to the very large investment in planting and planting stock required at the outset of the venture, as well as to the fertilization costs that recur in alternate years between harvests. On the other hand, the 4K system has a moderate initial investment, with a relatively short rotation.

Land Rented Option

In all the land rented options, the IRR was lower than in the land free option. In the 1K system, the annual rent of $52.50 is invested for a much longer time period. This was consistently a major factor in the low IRR for short rotation. The same trend is evident in both the 35K and 4K systems, although it becomes more pronounced as the rotation period becomes longer.

Factor Significance

Both 35K land free and land rented management systems are most affected by the initial outlays for stock and planting costs. The 4K and 1K land rented management systems are most affected by the land costs, while the land free option is most influenced by the site preparation and weed control costs.

WIA Option

The effect of a WIA agreement on the feasibility of hybrid poplar is to greatly increase the associated IRR. The terms of a WIA agreement are such that the total cost to the owner is decreased substantially while his revenues essentially are not affected. Applying a WIA agreement to the base case resulted in an increase in the IRR of approximately 25 per cent, 40 per cent and 30 per cent for systems 35K, 4K and 1K respectively, over the base case.

The WIA agreement option exhibits a positive influence on the financial feasibility of all hybrid poplar management systems.

Free Stock Option

The free stock option generally had only a marginal effect. It increased the IRR on the 35K system by approximately five per cent, due to the substantial costs of the intensive planting associated with this system. In the 4K and 1K management systems this option has a negligible effect on IRR due to the relatively low significance of stock costs in these rotations.

Yields

In all management systems, increasing the yield increases the IRR in a linear relationship. If yield per hectare is doubled, the IRR approximately doubles.

Harvests

Increasing the number of harvests obtained from one root system increases that system's IRR. For 4K and 1K management systems, the marginal increase in IRR diminished after six harvests. That is to say, after six harvests there is no appreciable increase in IRR to be gained by increasing the number of harvests. System 35K rotation does not overtly show this trend in this analysis, but it is expected that after approximately fifteen harvests, a reduction in the marginal increase of IRR would be exhibited.

Other Factors

Two major attractions of hybrid poplar plantation silviculture are:

- The ability to locate new plantations close to the mill, thereby reducing transportation costs.
- The lesser expense associated with harvesting plantation stock grown in rows and on level land, compared to that of naturally occuring mixed hardwoods.

In eastern Ontario, transportation savings can be in the order of $8/ODT. Harvesting cost savings are in the order of $5/ODT. Part or all of these savings can be added to the stumpage price to make poplar production financially attractive.

10 THE CONSUMER

One of the key considerations in planning and locating a large wood consuming industry is the availability of adequate supplies of raw material.

A processing facility is surrounded by an area from which it must draw an economic supply of wood. This area defines the "woodshed" for the mill.

The consumer is motivated to organize the woodshed so as to provide a continuous flow of wood to the mill at the least cost over the life of the mill. The establishment of fast-growing plantations allows the consumer increased flexibility in organizing a long-term wood supply. There is little consumer choice involved in the location of natural forests, although there is in the location of the mills in relation to the forest and other features. However, fast-growing plantations are subject to choices in location within the woodshed. The following least-cost woodshed model has been developed to determine optimal wood supply programs for a large consumer.

The Model

The objective of the woodshed model (Table 10-1) is to minimize the total cost of biomass delivered to the mill over a period of 25 years. This is done by optimizing the number of hectares of each management system harvested at varying distances from the mill each year. The model is used to provide a least-cost allocation.

The cost coefficient is the cost in dollars per hectare. This total cost includes a stumpage value, harvesting costs and transportation costs, from a particular location, to the mill. The area around the mill is considered to be a series of 10 concentric rings. There are 1 000 variables, four systems x 10 rings x 25 years = 1 000. Each cost coefficient is based on an oven-dry tonne (ODT) of biomass delivered to the mill. The yield is assumed to be 50 oven-dry tonnes per hectare for all systems at harvest.

The Contraints

There are three sets of constraints (Table 10-2) which must be satisfied in the model. A total of 285 constraint equations are considered in the solution of the model.

Table 10-1

The objective function for the woodshed model

OBJECTIVE FUNCTION:

MINIMIZE TOTAL WOOD COST
(WDC) OVER 25 YEARS

$$
\begin{aligned}
WDC = \sum_{y=1}^{25} \Big(\sum_{r=1}^{10} \Big[& (Try + Hy + S_{35K})50 \cdot X_{35Kry} \\
& + (Try + Hy + S_{4K})50 \cdot X_{4Kry} + \\
& (Try + Hy + S_{1K})50 \cdot X_{1Kry} + \\
& (Try + Hy + S_{N})50 \cdot X_{Nry} \Big] \Big)
\end{aligned}
$$

Variables:
x = number of hectares harvested
A = number of hectares available

Variable Coefficents:
T = transportation cost to move one oven-dry tonne of wood from the forest gate to the mill yard
H = harvesting cost to cut one oven-dry tonne of wood and forward to the roadside
S = Stumpage cost is either the cost of producing, or the cost of purchasing, one oven-dry tonne of wood

Subscripts:
y = years
r = ring number
35K = Fast-Growing Hardwoods Management System 35K
4K = Fast-Growing Hardwoods Management System 4K
1K = Fast-Growing Hardwoods Management System 1K
N = Natural forest area
P = Plantation area

Table 10-2

Sets of constraints for the woodshed model

1. ANNUAL WOOD SUPPLY (WS) REQUIREMENTS

$$\overset{25}{\underset{y=1}{\Big\{}} \text{WS} \leq \sum_{r=1}^{10} (50 \cdot X_{35\,Kry} + 50 \cdot X_{4Kry} + 50 \cdot X_{1Kry} + 50 \cdot X_{Nry}) \Big\}$$

2. HARVESTABLE AREA (A) OF NATURAL FOREST

$$\overset{10}{\underset{r=1}{\Big\{}} A_{NR} = \sum_{y=1}^{25} (X_{Nry}) \Big\}$$

3. HARVESTABLE AREA (A) OF PLANTATIONS BY MANAGEMENT SYSTEM

$$\overset{25}{\underset{y=1}{\Bigg\{}} \overset{10}{\underset{r=1}{\Big\{}} A_{Pry} = \sum_{y-1}^{y} (X_{35\,Kry}) + \sum_{y-4}^{y} (X_{4Kry}) + \sum_{y-9}^{y} (X_{1Kry}) \Big\} \Bigg\}$$

Wood Supply

Each year the total amount of wood harvested must be equal to or greater than the annual wood requirement of the mill. Various levels of harvest can be assumed for different sizes of consumers.

Natural Forest Area

The area of natural forest harvested must not exceed the total area available in any particular ring. Once cut, it cannot be reharvested during the 25-year period, since a rotation age of at least 40 years is assumed.

Plantation Forest Area

The total area of all plantations cut in a ring must not exceed the total area available. Any areas previously harvested cannot be re-cut until they are once again at rotation age. The assumed rotation ages for the 35K, 4K and 1K management systems are two, five and 10 years, respectively.

The Coefficients for the Model Variables

The objective functions and constraints form the basic framework of the model. Before this model can be solved, the values of coefficients in the equations must be calculated for a specific consumer from an assumed data set.

The Data - Profile of the Consumer

The consumer is a mill requiring 500,000 oven-dry tonnes of biomass per year. The mill is operating in a supply-limiting economy and must carefully design its procurement plans over the long term. The mill is technically capable of utilizing many different types of woody biomass. The wood supply consists of natural forest and three types of plantations of fast-growing hardwoods, as detailed in Table 10-3. Ten per cent of the landbase surrounding the mill is available natural forest that can be harvested only once, but at any time during the 25-year period. Forty-eight per cent of the landbase is suitable for growing fast-growing hardwoods (Table 10-4). The landbase has been divided into 10 concentric rings, each 10 km wide. The assumed average distance from each ring to the central location of the consumer, and the areas of each ring, are given in Table 10-5.

The total cost of an oven-dry tonne of wood delivered to the consumer is made up of three separate costs: stumpage costs, harvesting costs and transportation costs. Stumpage costs involve the costs of producing or buying standing wood and are specific to the type of wood source. The assumed stumpage costs ($/ODT) for the different sources of wood are given in Table 10-3. Stumpage costs for fast growing poplars are based on input costs documented in Chapter 9. It is assumed that stumpage costs are equal in all rings and will remain constant over the 25-year period. Harvesting costs are assumed to be equal for all wood sources and all rings. However, the harvesting costs have been indexed to the National Energy Pricing Policy

Table 10-3

Characteristics of the various biomass sources

Characteristic	Fast-growing hardwood plantations Management System 35K	4K	1K	Natural forest
Rotation (Years)	2	5	10	40
Yield at Harvest (oven dry tonnes/ha)	50	50	50	50
Stumpage cost/price ($ per oven dry tonne)	$34.45	$9.50	$10.30	$5.00

Table 10-4

Characteristics of the land base in the woodshed of the consumer

Land Type	Per cent of Total Area
Idle land suitable for establishment of fast-growing hardwoods	48
Forest available for harvest	10
Forest unavailable for harvest	10
Developed agricultural land	32
Total	100

Table 10-5

Characteristics of the rings in the woodshed

Ring Number	Radius distance from the mill (km)	Assumed average distance to the (km)	Plantation area available (ha)	Natural forest area available (ha)
1	0 - 10	5	15,080	3,142
2	10 - 20	15	45,239	9,425
3	20 - 30	25	75,398	15,708
4	30 - 40	35	105,558	21,991
5	40 - 50	45	135,717	28,274
6	50 - 60	55	165,876	34,558
7	60 - 70	65	196,035	40,841
8	70 - 80	75	226,195	47,124
9	80 - 90	85	256,354	53,407
10	90 - 100	95	286,513	59,690

Values give assumed transportation distance from each ring to the consumer; areas of natural forest and plantable plantation available for each ring.

(Energy, Mines and Resources, 1980) resulting in increasing harvesting costs over the 25-year period.

The following regression equation estimates the harvesting cost ($/ODT) for each year.

$$Y = 29.364\, e^{.067x}$$

Where: x = year, i.e., 1, 2, 3...25 of harvest
Y = harvesting cost in year x ($/ODT)

The transportation cost involves the cost of moving one ODT of wood from a specific ring to the mill in a specific year. Transportation costs vary from ring to ring and also over time. The transportation cost has also been indexed to the National Energy Pricing Policy, resulting in increased transportation costs each year. The transport cost is determined by using the regression equation for the appropriate year (Table 10-6) and by using the assumed average distance, in kilometres, to the mill (Table 10-5).

The equations given in Table 10-6 were calculated from data derived from the National Energy Pricing Policy (Table 10-7). The aim of this policy is to provide a stable setting for industrial planning and development and, therefore, it has been used in the structure of the woodshed model.

Results

A solution to the linear program was obtained which provided an optimal solution minimizing total wood cost.

The results are summarized in a schedule indicating by management system, ring and year the number of hectares cut. This schedule constitutes an optimal

Table 10-6

The cost of transporting the wood indexed to the National Energy Pricing Policy, resulting in an increasing cost over time

Year	Regression equation
1	$Y = 4.551 + 0.058x$
2	$Y = 4.552 + 0.059x$
3	$Y = 4.548 + 0.061x$
4	$Y = 4.550 + 0.063x$
5	$Y = 4.548 + 0.065x$
6	$Y = 4.550 + 0.067x$
7	$Y = 4.547 + 0.070x$
8	$Y = 4.548 + 0.073x$
9	$Y = 4.543 + 0.076x$
10	$Y = 4.546 + 0.081x$
11	$Y = 4.542 + 0.082x$
12	$Y = 4.538 + 0.091x$
13	$Y = 4.539 + 0.097x$
14	$Y = 4.539 + 0.104x$
15	$Y = 4.541 + 0.112x$
16	$Y = 4.514 + 0.122x$
17	$Y = 4.532 + 0.133x$
18	$Y = 4.528 + 0.145x$
19	$Y = 4.532 + 0.160x$
20	$Y = 4.527 + 0.176x$
21	$Y = 4.522 + 0.195x$
22	$Y = 4.504 + 0.217x$
23	$Y = 4.498 + 0.242x$
24	$Y = 4.497 + 0.271x$
25	$Y = 4.485 + 0.304x$

A set of regression equations is used to estimate the cost of transporting one oven-dry tonne of wood to the consumer. Y = cost of transporting one oven-dry tonne of wood to the consumer ($/ODT). x = the distance in km from the plantation to the mill (km).

Table 10-7

National Energy Program: wellhead oil prices

	Oil sands reference price*	Tertiary recovery oil** (15° API gravity)	Conventional oil (38° API gravity)
		($/bbl)	
Jan. 1980	-	-	14.75
Aug. 1980	-	-	16.75
Jan. 1981	38.00	30.00	17.75
July 1981			18.75
Jan. 1982	41.85	33.05	19.75
July 1982			20.75
Jan. 1983	45.80	36.15	21.75
July 1983			22.75
Jan. 1984	49.85	39.35	25.00
July 1984			27.25
Jan. 1985	54.10	42.70	29.50
July 1985			31.75
Jan. 1986	58.55	46.20	35.25
July 1986			38.75
Jan. 1987	63.20	49.90	42.25
July 1987			45.75
Jan. 1988	68.30	53.90	49.25
July 1988			52.75
Jan. 1989	73.75	58.20	56.25
July 1989			59.75
Jan. 1990	79.65	62.85	63.25
July 1990			66.75

Source: Energy, Mines and Resources, 1980

* Subject to cap of international price.

** In later years, the price of tertiary recovery oil will depend upon the price for conventional oil. As the price for conventional oil approaches that for tertiary recovery, price differentials will develop to reflect quality differences, i.e., the cost of upgrading. The price of tertiary recovery oil will never be less than the price for conventional oil of a similar quality.

allocation of the cut over the 25 year period. By modifying the wood supply (WS) constraint, three wood supply schedules were generated for consumers requiring 500,000 ODT/year, 1,000,000 ODT/year and 2,000,000 ODT/year. The schedules are given in Tables 10-8, 10-9 and 10-10 respectively.

Delivered wood costs ($/ODT), by mill size and by year, are given in Table 10-11. These values represent minimized cost per ODT of biomass delivered to the mill. All costs are given in constant 1980 dollars. No attempt has been made to account for inflation. However, harvesting and transportation costs are indexed to the National Energy Pricing Program and therefore increase at an average of 14.9 per cent per year.

Discussion

Table 10-8 shows the harvest allocation over a 25-year period for a mill demanding 500,000 ODT of wood/year. To meet the demand, all natural forests within a 70 km radius and most available plantation areas within a 20 km radius are harvested. From years one to eight, only natural forest is harvested. Starting in year nine, wood is harvested from plantations to help meet the demand. The program chooses system 4K as its first least-cost alternative to natural forest. Within a 10 km radius, system 4K is utilized to its maximum potential. Only half of the available area for plantations between 10 km and 20 km is required.

As wood demand is doubled to 1,000,000 ODT per year (Table 10-9) several changes are evident. The natural forest is harvested from a wider radius of 80 km from the mill. Plantations in the form of 4K are utilized starting in year five. As more plantations are needed,

Table 10-8

Optimal allocation of harvest cut for a 500,000 ODT/year consumer

	RING																			
	0-10 km		10- 20 km		20-30 km		30-40 km		40-50 km		50-60 km		60-70 km		70-80 km		80-90 km		90-100km	
Year harvested	4K	N	4K	N	4K	N	4K	N	4K	N	4K	N	4K	N	4K	N	4K	N	4K	N
1														10000						
2														10000						
3														10000						
4												9159		841						
5														10000						
6												10000								
7												10000								
8										4601		5399								
9	5080									4920										
10	10000																			
11										10000										
12								1247		8753										
13								10000												
14	5080		821*					4099												
15	10000																			
16			10000*																	
17			10000*																	
18						3355		6645												
19	5080					4920														

Values are for number of hectares to be harvested as solved in the woodshed model.

* Indicates not all available area in a ring and year was used.

Table 10-9

Optimal allocation of harvest cut for a 1,000,000 ODT/year consumer

	RING																			
	0-10 km		10-20 km		20- 30 km		30-40 km		40-50 km		50-60 km		60-70 km		70-80 km		80-90 km		90-100km	
Year harv-ested	4K	N	4K	N	4K	N	4K	N	4K	N	4K	N	4K	N	4K	N	4K	N	4K	N
1																20000				
2																20000				
3														12876		7124				
4														20000						
5	15080													4920						
6												16955		3045						
7			20000																	
8										2397		17603								
9			319							19681										
10	15080		4920																	
11			20000																	
12			20000																	
13								13804		6196										
14			319		11494*			8187												
15	15080		4920																	
16			20000																	
17			20000																	
18					4292*	15708														
19					20000*															
20	15080				4920*															
21					20000*															
22		3142		9425	7433*															
23			20000																	
24			20000																	
25	15080		4920																	

Values are for number of hectares to be harvested as solved in the woodshed model.

* Indicates not all available area in a ring and year was used.

Table 10-10

Optimal allocation of harvest cut for 2,000,000 ODT/year consumer

	RING																			
	0-10 km		10-20 km		20-30 km		30-40 km		40-50 km		50-60 km		60-70 km		70-80 km		80-90 km		90-100km	
Year Harvested	4K	N	4K	N	4K	N	4K	N	4K	N	4K	N	4K	N	4K	N	4K	N	4K	N
1			5239																	
2			40000																	34761*
3																				
4																		37089		2911*
5	15080				24920											23682		16318		
6			5239		15717															
7			40000													19044				
8																				
9					34761									35602		4398				
10	15080				24920									5239						
11			5239		15717		15468*					3576								
12			40000																	
13							40000*													
14					34761		5239*													
15	15080				24920															
16			5239		15717		19044*													
17			40000																	
18										9018		30982								
19					34761					5239										
20	15080				24920															
21					3992			21991		14017										
22		3142		9425	11725	15708														
23			40000																	
24			5239		34761															
25	15080				24920															

Values are for number of hectares to be harvested as solved in the Woodshed Model.

* Indicates not all available area in a ring and year was used.

Table 10-11

Cost per ODT of wood delivered to the mill
for three levels of demand over 25 years

	Level Mill Demand		
Year	500,000 ODT/year	1,000,000 ODT/year	2,000,000 ODT/year
1	44.72	45.30	46.44
2	46.96	47.54	48.50
3	49.42	49.63	52.54
4	51.47	52.04	52.92
5	54.82	55.27	56.23
6	57.12	57.22	58.98
7	60.34	62.02	62.02
8	63.42	63.67	64.56
9	66.36	66.66	69.41
10	71.84	72.04	72.85
11	74.72	76.68	77.57
12	79.13	81.02	81.02
13	83.10	83.40	87.80
14	89.10	90.64	91.80
15	94.82	95.10	96.22
16	101.62	101.62	105.41
17	107.74	107.74	107.74
18	112.20	112.21	115.26
19	119.08	122.92	122.75
20	127.04	127.91	129.23
21	133.80	138.80	137.19
22	140.30	143.11	143.61
23	154.74	154.74	154.74
24	163.30	164.68	167.03
25	172.28	173.03	176.07

Values are $/ODT.

all the area within a 20 km radius and some of the area between 20 km and 30 km is used.

When demand is again doubled to 2,000,000 ODT per year (Table 10-10) similar trends occur. The radius of natural forest harvested increases to within 100 km of the mill. Wood is harvested from plantations every year during the 25-year period. The area of plantation utilized increases to within a 40 km radius.

Generally, harvest activity moves closer to the mill, over time, as a direct result of energy indexing.

Table 10-11 shows the cost/ODT of delivered wood to the mill for each of the three demand situations. The very slight increase in cost/ODT with doubling and quadrupling demand shows that slack exists in the system as presented. Increasing the wood demand does not place a high financial burden on the mill. The increase in wood cost for the 500,000 ODT per year mill from $44.72/ODT to $172.28 ODT within 25 years is a result of energy price indexing in a resource constrained economy.

Conclusions

The output and discussion are valid only for the data, assumptions and constraints used. Individual consumers may find quite different results for their particular set of circumstances.

The model as presented does have a universal aspect: constraints can be changed, new data supplied and working group costs and area substituted for management system costs and area.

Within the context of energy price indexing in a resources constrained economy, the trade-off between transportation costs and growing (stumpage) costs has been examined for three mill sizes. For the purposes of the study, harvesting costs were assumed to be equal for all systems. This, of course, may not be true in the real world.

With the model developed, it is possible to conduct a sensitivity analysis and examine the relative effect of varying each of the inputs and altering each of the constraints. This work will be completed as part of Joint Action (Planning Group B) 26, "Planning For Large Scale Plantations" for the International Energy Agency.

APPENDICES

APPENDIX 1

Scientific Review August 17 to 21, 1981

The Review Panel met with Ministry staff in Ottawa, Monday, August 17, 1981 and were welcomed on behalf of Canada by F.L.C. Reed, Assistant Deputy Minister, Canadian Forestry Service and for the province by W.T. Foster, Deputy Minister, Ontario Ministry of Natural Resources.

After an illustrated presentation of the hybrid poplar program in eastern Ontario was made to the group, the panel visited the G. Howard Ferguson Forest Station at Kemptville and various trials and operational plantations in the eastern Region.

The formal review was held in public in Toronto on Wednesday and Thursday, August 19 and 20. The review was opened by the Minister of Natural Resources, the Honourable Alan W. Pope, who welcomed guests to the review and noted that such a public audit of this program, in which technological development was placed before interested persons and groups was most desirable. The 10 papers which comprise this publication were presented by their respective authors. Following the presentations, members of the review panel asked questions and discussed the presentations. Each panelist then gave his perception of the future of hybrid poplar silviculture. Finally, the meeting was opened to the audience for questions and general discussion.

The review panel met on August 21 to provide a critique and analysis of the program to senior Ministry staff which has proven helpful in planning the program and also in providing advice concerning the most effective manner of holding future public reviews of scientific and technolgoical programs.

Participants in the Scientific Review

Chairman - W.T. Foster, Deputy Minister
Ontario Ministry of Natural Resources

Organizer - M.F. Walmsley, Chief Scientist
Ontario Ministry of Natural Resources

The Review Panel

K.A. Armson	Chief Forester, Ontario Ministry of Natural Resources	Canada (Ontario)
A. Franclet	Director, AFOCEL, Association	France
E. Giordano	Silviculture Professor Centro Di Sperimentazione	Italy
R. Koster	Research Scientist, Research Institute for Forestry and Landscape Planning	Netherlands
R.P. Overend	Task Co-ordinator, Renewable Energy, National Research Council	Canada
G. Siren	Professor, Energy Forestry Project, The Swedish University of Agricultural Sciences	Sweden
V. Steenackers	Research Scientist, Ministry Van Landbouw	Belgium
F.R. Stettler	Professor, Forest Genetics University of Washington	USA
G. Vallee	Research Scientist, Quebec Ministere de L'Energie et Ressources	Canada (Quebec)
W.P. Weber	Supervisor, Fitler Managed Forest, Crown Zellerbach	USA

H. Weisgerber	Director, Institute of Hann. Munden	Germany
L. Zsuffa	Forest Geneticist, Ontario Ministry of Natural Resources	Canada (Ontario)

Scientific Review Presenters

B.A. Barkley	Ontario Ministry of Natural Resources
A.J. Campbell	Ontario Ministry of Natural Resources
L. Clay	Ontario Ministry of Treasury and Economics
R.W. Evers	Ontario Ministry of Natural Resources
R. Gardner	Ontario Ministry of Treasury and Economics
I. Lyon	Ontario Ministry of Treasury and Economics
W.E. Raitanen	Ontario Ministry of Natural Resources

The Audience

P.L. Aird	University of Toronto
I. Altosaar	University of Ottawa
H. Anderson	Ontario Ministry of Natural Resources
J.W. Andresen	University of Toronto
P.E. Anslow	Ontario Ministry of Natural Resources
D.O. Babin	Ontario Ministry of Agriculture and Food
D.E. Barron	Canadian Pulp and Paper Association
A. Beckwith	Ontario Ministry of Natural Resources
C. G. Bell	Great Lakes Forest Products Ltd.
R.J. Bevis	Canertech Inc.
I.D. Bird	Algonquin Forestry Authority
D. Boocock	University of Toronto
J. Briere	FERIC
J.D. Brophy	Ontario Paper Co.
E. Brubaker	Ontario Ministry of Agriculture and Food

J. Bryce	Domtar Inc.
D. Burger	Ontario Ministry of Natural Resources
F. Burrows	J.H. Normick Inc.
J. Cameron	Imperial Oil Ltd.
A.J. Campbell	Ontario Ministry of Natural Resources
D.J. Chapeskie	Ontario Ministry of Natural Resources
D. Cope	Ontario Ministry of Natural Resources
H. deVries	Ontario Ministry of Natural Resources
R.C. Dobbs	Canadian Forestry Service
A.J. Dolenko	Canadian Department of Energy, Mines and Resources
D. Drysdale	Ontario Ministry of Natural Resources
O. Emile	Quebec Ministere de l'Energie et Ressources
H. Falkner	Sir Sanford Fleming College
R. Fry	Ontario Ministry of Energy
E. Gage	Ontario Ministry of Natural Resources
G.J. Garner	Boise Cascade Canada Ltd.
C. Haxell	Ontario Ministry of Natural Resources
C.J. Heeney	Ontario Ministry of Natural Resources
P. Heroux	Instit de Recherches de Hydro-Quebec
G. Higham	Ontario Ministry of Natural Resources
M.R. Innes	Abitibi-Price Inc.
R. Johnson	Domtar Inc.
A.J. Kayll	Lakehead University
B. Keir	Ontario Ministry of Energy
B. Kerr	Canadian Department of Industry, Trade and Commerce
J. Korkonen	Ontario Forest Research Centre
L. Lambert	Ontario Ministry of Natural Resources
R.H. Leech	Ontario Ministry of Natural Resources
D.V. Love	University of Toronto

F.C. Lozano	Ontario Ministry of Natural Resources
G. Mallette	Waferboard Corporation
E. Marcus	Ontario Ministry of Natural Resources
J. Michell	Ontario Ministry of Natural Resources
T. Moore	Petawawa National Forestry Institute
L. Moran	University of Toronto
R. Morin	Ontario Ministry of Natural Resources
F. Moritsugu	Ontario Ministry of Natural Resources
P. Morley	Lamb, Guay, Inc.
R. Morris	North American Poplar Council
V.J. Nordin	University of Toronto
J.R. Oatway	Ontario Ministry of Natural Resources
A. Peacock	Ontario Ministry of Natural Resources
R. Perrott	University of Guelph
T. Phillips	University of Guelph
G. Pierpoint	Ontario Ministry of Natural Resources
D. Reilly	Ontario Hydro
E.T. Reynolds	Ontario Ministry of Natural Resources
L.F. Riley	Great Lakes Forest Research Centre
R. Rivard	Ministry of Northern Affairs
R. Sequin	University of Guelph
R. Silversides	National Research Council
A. Sugden	Ontario Research Foundation
B.A. Summers	National Research Council
H.S.D. Swan	Consultant
R. Tallim	Ontario Energy Corporation
V. Timmer	University of Toronto
H. Vanner	Ontario Energy Corporation
H.F. VonCube	Ontario Ministry of Northern Affairs
W. Warburton	Ottawa Citizen
B. Warwick	Ontario Ministry of Natural Resources
B. Wreu	Kemptville College of Agriculture
J. Zabinski	Celanese, Canada

APPENDIX 2

Documentation of Stool Bed Management in Compartment 71 at Kemptville, Ontario

A. Past Use, Site Preparation and Planting

Year	Activity
1948-1967	Fall rye production
1967-1978	Production of white spruce super seedlings for proposed seed production area.
1978	Site preparation for hybrid poplar stool beds. - cultivation (over summer) - triple super phosphate -1120kg/ha - potassium sulphate - 448kg/ha - magnesium sulphate - 112kg/ha - dolomitic limestone -1120kg/ha - chlorodane 25G - 22kg/ha
1979	Plant - unrooted cuttings and mini-cuttings (May)(1.0M x 0.3M)

B. Soil analysis over time

Year	pH	Texture	Organic Carbon	% O.M.	N	P	K	Ca	Mg	C.E.C.
1977	6.1	7-2-1	3.06	5.1	0.2	3.00	0.11	2.97	0.47	10.75
1978	5.7	7-2-1	2.19	3.6		13.30	0.17	9.04	1.40	13.50
1979	6.1	7-2-1	2.85	4.8		20.67	0.42	6.16	1.00	-
1980	6.1	7-2-1	2.64	4.4		13.80	0.38	4.21	1.03	7.25

C. Weed Control

1979 - early May	Enide @ 8.8 kg/ha (boom spray)
1980 - early May	Enide @ 8.8 kg/ha (boom spray)
	Roundup @ 4.4 kg/ha (boom spray)
1979 and 1980	manual weeding (June - September)

D. Pest Management

Malathion 50%	1979: nine applications of 1.4 L/ha per application, June 8 - August 30. 1980: twelve applications 1.4 L/ha per application, June 4 - August 25.

E. Soil Fertility Amendments Schedule

Date Mo	Day	N	P	K	Ca	Mg	Commercial Mix N	P	K	Kg/ha	Remarks
		kg/ha (elemental)									
1979											
05	17	22									
05	22	22									
06	01	22		27							
06	15	22					11	54	0	430	
06	25	22		27							
06	27	22									
07	04	22		27							
07	12	22									
07	18	22									
08	03	22		27							
Total		220									
1980											
04	23	40		68	499		0	0	22	85	11%Mg 22%S
05	23						11	54	0	384	
04	30	20									
05	07	20									
05	14	20									
05	20	20									
05	22						0	0	22	85	11%Mg 22%S
05	23			20							
05	27	20									
06	04	20					11	514	0	384	
06	13	20									
06	18	20		34							
06	19						0	0	22	103	11%Mg 22%S
06	27	20									
06	30	20									
07	10	20									
07	15	20									
07	16			20							
Total		280		142							

F. Typical Irrigation Schedule (e.g. June 1980)

Date of Application	Application Rate (cm)
5	8.3
6	12.7
9	6.3
13	12.7
17	25.9
19	8.3
23	25.0
26	25.0
27	12.7
Total for June	136.9
Average	15.2

Average: 1.52 cm. irrigation every 3-4 days.

Last date application in 1980: August 15.

APPENDIX 3

Effectiveness of Herbicide Treatments in Year Two with all Treatment Results Expressed as a Ratio of the Control

$$\text{The Ratio} = \frac{\text{Mean Cumulative Height per year per treatment}}{\text{Mean Cumulative Height per plot for control}}$$

Treatment Chemical Rate (kg/ha (lb/ac))	Grenville 7d(3) (1977)			Domtar 11('78)	Grenville 34A (1978)	Grenville 34B (1978)		
	DN22	DN1	JAC4	145/5	DN2	DN74	DTAC1	DN16
Control	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Amizine .56 (0.5)					2.96			
1.12 (1.0)					3.12			
2.24 (2.0)					3.39			
3.92 (3.5)					3.66			
"					2.58			
"					2.18			
"					2.67			
"					2.46			
"					2.91			
"					2.26			
8.96 (8.0)					1.65			
Atrazine 1.12 (1.0) & Alachlor .56(0.5)	2.27	2.18	1.85		3.17			
1.12(1.0)	2.23	1.96	1.82		3.40			
2.24(2.0)	3.19	1.28	1.61		2.87			
4.48(4.0)	2.87	2.15	1.81		1.90			
Cyanazine .56 (0.5)	1.65	1.38	1.54					
1.12 (1.0)	1.22	1.48	1.86					
2.24 (2.0)	2.78	1.75	1.46					
4.48 (4.0)	2.45	2.01	1.21					
8.96 (8.0)	2.06	2.10	1.87					
Cyanazine 4.48 (4.0) & Atrazine .56 (0.5)				2.10				
1.12 (1.0)				2.34				
2.24 (2.0)				2.20				
4.48 (4.0)				.58				
8.96 (8.0)				0.51				

Treatment Chemical Rate (kg/ha (lb/ac))	Grenville 7d(3) (1977)			Domtar 11('78)	Gren-ville 34A (1978)	Grenville 34B (1978)		
	DN22	DN1	JAC4	145/51	DN2	DN74	DTAC1	DN16
Cyanazine 4.48 (4.0) & Alachlor .56 (0.5)				2.31				
1.12 (1.0)				2.14				
2.24 (2.0)				2.23				
4.48 (4.0)				1.73				
8.96 (8.0)				1.73				
Cyanazine 4.48 (4.0) & Terbacil .28 (0.25)				2.27				
.56 (0.50)				2.17				
1.12 (1.00)				2.11				
2.24 (2.00)				2.56				
4.48 (4.00)				1.74				
C.G.A. 18762 .28 (0.25)						1.23	1.04	.87
4.48 (4.00)						.63	.51	.52
Diuron .56 (0.5)					3.44			
1.12 (1.0)					3.05			
2.24 (2.0)					2.51			
"					2.70			
"					2.64			
"					3.02			
"					2.33			
"					2.00			
"					2.42			
4.48 (4.0)					2.32			
8.96 (8.0)					1.69			

Treatment Chemical Rate (kg/ha (lb/ac))		Grenville 7d(3) (1977)		Domtar 11('78)	Gren-ville 34A (1978)	Grenville 34B (1978)		
	DN22	DN1	JAC4	145/51	DN2	DN74	DTAC1	DN16
Diuron 1.68 (1.5) & Napropamide .56 (0.5)				2.41				
1.12 (1.0)				1.93				
2.24 (2.0)				1.95				
4.48 (4.0)				2.05				
8.96 (8.0)				2.22				
Diuron 1.68 (1.5) & Diphenamid 1.12 (1.0)	1.03	2.06	1.70					
2.24 (2.0)	2.45	1.80	1.55					
4.48 (4.0)	2.43	2.08	2.28					
8.96 (8.0)	1.02	1.90	2.19					
Diuron 1.12(1.0) & Simazine .56 (0.5)						1.00	.86	.60
1.12 (1.0)						.98	.97	.84
2.24 (2.0)						.99	.70	.80
3.92 (3.5)						.95	.98	.78
8.96 (8.0)						1.24	.95	.73
Metolachlor .56 (.5)						.60	.66	.49
1.12 (1.0)						.69	.54	.46
2.24 (2.0)						1.05	.99	.93
4.48 (4.0)						1.22	.99	.76
8.96 (8.0)						.95	.81	.63
EPTC 8.96 (8.0) & Metribuzin .28 (0.25)						.56	.64	.60
1.12 (1.00)						.83	.83	.78
4.48 (4.00)						.86	.87	.83

Treatment Chemical Rate (kg/ha (lb/ac))	Grenville 7d(3) (1977)			Domtar 11(1978)	Gren- ville 34A (1978)	Grenville 34B (1978)		
	DN22	DN1	JAC4	145/5	DN2	DN74	DTAC1	DN16
Alachlor .28 (0.25)						1.22	1.07	.98
1.12 (1.00)						1.19	1.11	.88
4.48 (4.00)						.98	.95	.62
Alachlor 2.24 (2.0) and Atrazine .28 (0.25)					3.17			
.56 (0.50)					3.40			
1.12 (1.00)					2.87			
2.24 (2.00)					1.90			
Metribuzin .28 (.25)	1.84	1.43	1.48			.87	.78	.58
.56 (.5)	1.09	1.00	1.11			.98	.93	.69
1.12 (1.0)	2.10	1.81	1.58			.63	.62	.57
2.24 (2.0)	1.65	1.34	1.18			.59	.79	.41
4.48 (4.0)	.72	1.30	.47			1.41	1.13	.95
8.96 (8.0)	.65	.52	.22			1.02	.92	.69
Metribuzin .56 (.5) and Diphenamid 1.12 (1.0)	1.97	1.50	1.48					
2.24 (2.0)	2.41	1.72	1.90					
4.48 (4.0)	1.63	1.73	1.61					
8.96 (8.0)	2.12	1.91	1.17					
Linuron .28 (0.25)						.68	.89	.62
.56 (0.5)	1.90	.92	1.06					
1.12 (1.0)	1.38	1.19	1.33			.85	.77	.51
2.24 (2.0)	1.64	1.79	1.82					
4.48 (4.0)	.85	1.99	1.23			1.30	1.00	.73
8.96 (8.0)	0	1.21	.18					

Treatment Chemical Rate (kg/ha (lb/ac))	Grenville 7d(3) (1977)			Domtar 11('78)	Grenville 34A (1978)	Grenville 34B (1978)		
	DN22	DN1	JAC4	145/5	DN2	DN74	DTAC1	DN16
Linuron 2.24 (2.0) And Amitrole .56 (0.5)				2.45				
1.12 (1.0)				2.26				
2.24 (2.0)				1.86				
4.48 (4.0)				2.19				
8.96 (8.0)				1.72				
Linuron 2.24 (2.0) and Diphenamid .56 (0.50)				2.44				
1.12 (1.00)				2.17				
2.24 (2.00)				2.25				
4.48 (4.00)				1.90				
8.96 (8.00)				1.79				
Linuron 1.12 (1.0) & Alachlor .56 (0.5)	2.06	2.07	1.89					
1.12 (1.0)	1.95	1.53	1.09					
2.24 (2.0)	1.68	1.63	1.54					
4.48 (4.0)	1.77	1.91	1.87					
Linuron 2.24 (2.0) and Alachlor .56 (0.5)						.99	1.01	.86
1.12 (1.0)						.64	.60	.55
2.24 (2.0)						1.10	.97	.78
4.48 (4.0)						.93	.67	.48
8.96 (8.0)						.83	.73	.58
Chlorbromuron .56 (0.5)	1.79	1.25	1.19			.88	.84	.67
1.12 (1.0)	2.56	1.87	1.42			1.13	.95	.56
2.24 (2.0)	1.97	2.09	2.12			1.04	.91	.77
4.48 (4.0)	2.00	1.95	1.12			1.06	1.04	.83
8.96	.48	1.46	.30			1.06	.89	.67
17.92 (16.0)	.12	.46	.01					

Treatment Chemical Rate (kg/ha (lb/ac))		Grenville 7d(3) (1977)			Domtar 11('78)	Gren-ville 34A (1978)	Grenville 34B (1978)		
		DN22	DN1	JAC4	145/5	DN2	DN74	DTAC1	DN16
Simazine 1.12 (1.0) & Napropamide	.56 (0.5)					3.33			
	1.12 (1.0)					3.70			
	2.24 (2.0)					3.63			
	4.48 (4.0)					3.54			
	"					2.79			
	"					2.22			
	"					2.19			
	"					2.76			
	"					2.44			
	8.96 (8.0)					3.30			
						3.96			
Simazine 1.12 (1.0) and Diuron 0							.82	.74	.60
"	.28 (0.25)						1.15	.72	.81
"	.56 (0.50)						.86	.78	.67
"	1.12 (1.00)						1.29	1.17	.98
"	4.48 (4.00)						.87	.77	.75
Simazine 2.24 (2.0) & Metolachlor	.56 (0.5)				2.88				
	1.12 (1.0)				2.45				
	2.24 (2.0)				2.44				
	4.48 (4.0)				2.02				
	8.96 (8.0)				2.48				
Simazine 1.12 (1.0) & Diphenamid	.56 (0.5)					3.68			
	1.12 (1.0)					4.05			
	2.24 (2.0)					3.40			
	4.48 (4.0)					2.93			
	8.96 (8.0)					3.21			

Treatment Chemical Rate (kg/ha (lb/ac))	Grenville 7d(3) (1977)			Domtar 11('78)	Gren-ville 34A (1978)	Grenville 34B (1978)		
	DN22	DN1	JAC4	145/5	DN2	DN74	DTAC1	DN16
Chlorbromuron 2.24 (2.0) & Metolachlor .56 (0.5)						.94	.94	.86
1.12 (1.0)						.88	.99	.75
2.24 (2.0)						.69	.60	.56
4.48 (4.0)						1.47	1.11	.99
8.96 (8.0)						1.04	.85	.68
Chlorbromuron 2.24 (2.0) Alachlor .56 (0.5)				2.85				
1.12 (1.0)				2.00				
2.24 (2.0)				2.56				
4.48 (4.0)				2.45				
8.96 (8.0)				2.02				
Mechanical				1.27	1.39	.75	.76	.84
"					.87			
"					1.30			
"					1.41			
"					1.02			
Metobromuron .56 (0.5)	2.28	1.64	1.78					
1.12 (1.0)	2.26	1.85	1.20					
2.24 (2.0)	1.73	1.67	1.48					
4.48 (4.0)	1.45	1.90	1.70					
8.96 (8.0)	.49	1.62	.91					
17.92 (16.0)	.12	.64	0					
Simazine .56 (0.5)	3.52	1.93	1.53		2.27			
1.12 (1.0)					3.25			
2.24 (2.0)	2.40	1.81	2.15		3.23			
4.48 (4.0)	2.88	2.18	1.75		2.78			
8.96 (8.0)					1.09			

Treatment Chemical Rate (kg/ha (lb/ac))		Grenville 7d(3) (1977)			Domtar 11('78)	Grenville 34A (1978)	Grenville 34B (1978)		
		DN22	DN1	JAC4	145/51	DN2	DN74	DTAC1	DN16
Simazine 1.12 (1.0) & Metribuzin	.28 (0.25)	1.78	2.04	1.35					
	1.12 (1.00)	1.78	1.84	1.06					
	2.24 (2.00)	2.18	2.12	1.62					
	4.48 (4.00)	1.59	1.57	1.11					
Simazine 2.24 & Metribuzin	.56 (0.5)				2.00				
	1.12 (1.0)				1.95				
	2.24 (2.0)				1.50				
	4.48 (4.0)				.87				
	8.96 (8.0)				.13				
Simazine 1.12 (1.0) & Linuron	.56 (0.5)	2.41	1.87	1.40					
"	1.12 (1.0)	1.02	1.48	1.34					
"	2.24 (2.0)	2.06	1.57	1.42					
"	4.48 (4.0)	.25	1.80	.96					
"									
Simazine 3.36 (3.0) & Glyphosate	1.12 (1.0)				2.34				
	2.24 (2.0)				2.46				
Simazine 1.12 (1.0) & Terbacil	.28 (0.25)	2.89	1.92	1.56					
	.56 (0.50)	2.30	1.64	1.93					
	1.12 (1.00)	2.13	1.83	1.75					
	2.24 (2.00)	2.47	2.11	1.98					
	4.48 (4.00)	3.06	2.33	1.61					

Treatment Chemical Rate (kg/ha (lb/ac))		Grenville 7d(3) (1977)			Domtar 11('78)	Gren-ville 34A (1978)	Grenville 34B (1978)		
		DN22	DN1	JAC4	145/5	DN2	DN74	DTAC1	DN16
Terbacil	.28 (0.25)						1.16	1.04	.89
	.56 (0.50)						.92	.76	.71
	1.12 (1.00)						1.29	1.00	.87
	2.24 (2.00)						.84	.83	.73
	4.48 (4.00)						.99	.80	.73
Butylate	8.96 (8.0 & Diphenamid .56 (0.5)				1.09				
	1.12 (1.0)				1.03				
	2.24 (2.0)				.48				
	4.48 (4.0)				1.75				
	8.96 (8.0)				1.32				

APPENDIX 4

Effectiveness of Herbicide Treatments in Year Three with all Treatment Results Expressed as a Ratio of the Control

Treatment Chemical Rate (kg/ha (lb/ac))	Grenville 7d(3) (1977)			Domtar 11('78)	Grenville 34A (1978)	Grenville 34B (1978)		
	DN22	DN1	JAC4	145/51	DN2	DN74	DTAC1	DN16
Control	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Amizine .56 (.5)					3.18			
1.12 (1.0)					3.10			
2.24 (2.0)					3.42			
3.92 (3.5)					3.76			
"					2.81			
"					2.16			
"					2.90			
"					2.62			
"					2.97			
"					2.39			
8.96 (8.0)					1.44			
Atrazine 1.12 (1.0) & Alachlor .56(.5)	2.72	2.04	1.40					
1.12(1.0)	2.50	1.92	1.57					
2.24(2.0)	2.47	1.73	1.11					
4.48(4.0)	2.88	2.02	1.62					
Cyanazine .56 (.5)	1.57	1.07	1.07					
1.12 (1.0)	2.18	1.60	1.42					
2.24 (2.0)	2.38	1.73	1.47					
4.48 (4.0)	2.04	1.96	.75					
8.96 (8.0)	2.33	1.90	1.40					
Cyanazine 4.48 (4.0) & Atrazine .56 (.5)				1.91				
1.12 (1.0)				2.26				
2.24 (2.0)				2.12				
4.48 (4.0)				.46				
8.96 (8.0)				.46				

Treatment Chemical Rate (kg/ha (lb/ac))	Grenville 7d(3) (1977)			Domtar 11('78)	Gren-ville 34A (1978)	Grenville 34B (1978)		
	DN22	DN1	JAC4	145/5	DN2	DN74	DTAC1	DN16
Cyanazine 4.48 (4.0) & Alachlor .56 (.5)				2.12				
1.12 (1.0)				2.05				
2.24 (2.0)				2.19				
4.48 (4.0)				1.60				
8.96 (8.0)				1.77				
Cyanazine 4.48 (4.0) & Terbacacil .28 (.25)				2.13				
.56 (. 5)				1.93				
1.12 (1.0)				1.93				
2.24 (2.0)				2.35				
4.48 (4.0)				1.67				
C.G.A. 18762 .28 (.25)						1.02	1.22	1.25
4.48 (4.0)						.42	.58	.81
Diuron .56 (.5)					3.75			
1.12 (1.0)					3.28			
2.24 (2.0)					2.45			
"					2.87			
"					2.55			
"					3.05			
"					2.60			
"					2.14			
"					2.51			
4.48 (4.0)					2.38			
8.96 (8.0)					.53			

Treatment Chemical Rate (kg/ha (lb/ac))	Grenville 7d(3) (1977)			Domtar 11('78)	Grenv- ville 34A (1978)	Grenville 34B (1978)		
	DN22	DN1	JAC4	145/51	DN2	DN74	DTAC1	DN16
Diuron 1.68 (1.5) & Napropamide .56(.5)				2.28				
1.12 (1.0)				1.86				
2.24 (2.0)				1.83				
4.48 (4.0)				1.95				
8.96 (8.0)				2.19				
Diuron 1.68 (1.5) & Diphenamide 1.12 (1.0)	1.69	1.86	1.24					
2.24 (2.0)	2.85	1.20	1.14					
4.48 (4.0)	3.07	2.10	1.42					
8.96 (8.0)	1.63	1.84	1.48					
Diuron 1.12(1.0) & Simazine .56 (.5)						.43	.82	.76
1.12 (1.0)						.76	.42	.76
2.24 (2.0)						1.23	1.06	1.34
3.92 (3.5)						.75	1.19	1.34
8.96 (8.0)						.84	.91	1.32
Metolachlor .56 (.5)						.81	.97	.87
1.12 (1.0)						.91	.92	.82
2.24 (2.0)						1.09	1.14	1.16
4.48 (4.0)						1.04	1.24	.94
8.96 (8.0)						.51	.57	.77
EPTC 8.96 (8.0) & Metribuzin m.28 (.25)						.71	.82	.60
1.12 (1.0)						1.09	1.17	1.17
4.48 (4.0)						.87	1.23	1.03

Treatment Chemical Rate (kg/ha (lb/ac))	Grenville 7d(3) (1977)			Domtar 11('78)	Grenv-ville 34A (1978)	Grenville 34B (1978)		
	DN22	DN1	JAC4	145/51	DN2	DN74	DTAC1	DN16
Alachalor .28 (.25)						.98	1.05	1.07
1.12 (1.00)						.87	.93	.87
4.48 (4.00)						.78	.77	.93
Alachalor 2.24 (2.0) and Atrazine .28 (.25)					3.24			
.56 (.50)					3.31			
1.12 (1.00)					2.68			
2.24 (2.00)					1.88			
Metribuzin .28 (.25)	1.80	1.58	1.47			.92	.85	.97
.56 (.5)	1.32	.99	.90			1.02	.71	.90
1.12 (1.0)	2.19	1.75	1.41			.78	.89	.86
2.24 (2.0)	1.85	1.29	.86			1.01	.92	1.11
4.48 (4.0)	.84	1.15	.32			1.21	.91	1.59
8.96 (8.0)	.72	.47	.15			.88	.96	1.12
Metribuzin .56 (.5) and Diphenamide 1.12 (1.0)	2.07	1.63	1.26					
2.24 (2.0)	2.30	1.66	1.42					
4.48 (4.0)	2.41	1.58	1.26					
8.96 (8.0)	1.74	1.87	1.37					
Linuron .28 (. 25)						.72	.91	.85
.56 (.5)	2.21	1.32	1.26					
1.12 (1.0)	1.56	1.20	.99			.57	.74	.46
2.24 (2.0)	2.17	1.68	1.20					
4.48 (4.0)	1.11	1.93	.89			.88	1.07	1.18
8.96 (8.0)	.07	.78	.09					

Treatment Chemical Rate (kg/ha (lb/ac))	Grenville 7d(3) (1977)			Domtar 11('78)	Grenville 34A (1978)	Grenville 34B (1978)		
	DN22	DN1	JAC4	145/51	DN2	DN74	DTAC1	DN16
Linuron 2.24 (2.0) And Amitrole .56 (.5)				2.37				
1.12 (1.0)				1.96				
2.24 (2.0)				1.76				
4.48 (4.0)				2.02				
8.96 (8.0)				1.70				
Linuron 2.24 (2.0) and Diphenamide .56 (.50)				2.25				
1.12 (1.00)				2.15				
2.24 (2.00)				2.31				
4.48 (4.00)				1.82				
8.96 (8.00)				1.78				
Linuron 1.12 (1.0) & Alachlor .56 (.5)	1.89	1.87	1.59					
1.12 (1.0)	1.81	1.54	1.23					
2.24 (2.0)	2.03	1.51	1.30					
4.48 (4.0)	2.46	1.60	1.21					
Linuron 2.24 (2.0) and Alachlor .56 (.5)						.95	1.17	1.26
1.12 (1.0)						.86	.87	.84
2.24 (2.0)						.99	1.05	1.15
4.48 (4.0)						.61	.71	.80
8.96 (8.0)						.88	1.10	1.35
Chlorbromuron .56 (.5)	2.16	1.31	1.15			.80	.84	.90
1.12 (1.0)	2.40	1.85	1.58			.93	.91	1.11
2.24 (2.0)	2.74	1.86	1.61			.59	.61	.77
4.48 (4.0)	1.08	1.84	1.22			1.13	1.08	1.19
8.96	.23	1.20	.23			.97	1.09	1.24
17.92 (16.0)	.17	.49	.13					

Treatment Chemical Rate (kg/ha (lb/ac))	Grenville 7d(3) (1977)			Domtar 11('78)	Grenv- ville 34A (1978)	Grenville 34B (1978)		
	DN22	DN1	JAC4	145/51	DN2	DN74	DTAC1	DN16
Chlorbromuron 2.24 (2.0) & Metolachlor .56 (.5)						.85	.94	.90
1.12 (1.0)						.64	.88	.86
2.24 (2.0)						.49	.52	.47
4.48 (4.0)						1.29	1.24	1.45
8.96 (8.0)						.61	.85	.81
Chlorbromuron 2.24 (2.0) Alachlor .56 (.50)				2.58				
1.12 (1.00)				1.80				
2.24 (2.00)				2.28				
4.48 (4.00)				2.20				
8.96 (8.00)				1.97				
Mechanical				1.14	1.43	.97	.84	.81
"					.96			
"					1.09			
"					1.29			
"					1.05			
Metobromuron .56 (.5)	2.75	1.72	1.10					
1.12 (1.0)	1.85	1.76	1.56					
2.24 (2.0)	1.92	1.73	1.19					
4.48 (4.0)	2.37	1.76	1.05					
8.96 (8.0)	1.32	1.58	.38					
17.92 (16.0)	.26	.59	0					
Simazine .56 (.5)	2.51	1.89	1.75		2.37			
1.12 (1.0)					3.13			
2.24 (2.0)	2.78	1.73	1.80		2.13			
4.48 (4.0)	3.05	1.84	.93		2.71			
8.96 (8.0)					1.18			

Treatment Chemical Rate (kg/ha (lb/ac))	Grenville 7d(3) (1977)			Domtar 11('78)	Grenville 34A (1978)	Grenville 34B (1978)		
	DN22	DN1	JAC4	145/51	DN2	DN74	DTAC1	DN16
Simazine 1.12 (1.0) & Napropamide .56 (.5)					3.31			
1.12 (1.0)					3.67			
2.24 (2.0)					3.72			
4.48 (4.0)					3.27			
"					2.63			
"					2.26			
"					2.26			
"					3.05			
"					2.51			
8.96 (8.0)					3.48			
					1.18			
Simazine 1.12 (1.0) and Diuron 0						.70	.68	.75
" .28 (.25)						1.15	1.07	1.40
" .56 (.5)						.53	.25	.45
" 1.12 (1.0)						1.01	.89	1.07
" 4.48 (4.0)						.79	.94	.85
Simazine 2.24 (2.0) & Metolachlor .56 (.5)				2.57				
1.12 (1.0)				2.34				
2.24 (2.0)				2.28				
4.48 (4.0)				2.05				
8.96 (8.0)				2.26				
Simazine 1.12 (1.0) & Diphenamide .56 (.5)					2.61			
1.12 (1.0)					3.97			
2.24 (2.0)					3.40			
4.48 (4.0)					3.02			
8.96 (8.0)					3.29			

Treatment Chemical Rate (kg/ha (lb/ac))	Grenville 7d(3) (1977)			Domtar 11('78)	Grenv-ville 34A (1978)	Grenville 34B (1978)		
	DN22	DN1	JAC4	145/5	DN2	DN74	DTAC1	DN16
Simazine 1.12 (1.0) & Metribuzin .28 (.25)	2.13	1.87	1.50					
1.12 (1.0)	2.31	1.62	.85					
2.24 (2.0)	2.77	1.86	1.26					
4.48 (4.0)	2.04	1.43	.76					
Simazine 2.24 & Metribuzin .56 (.5)				1.92				
1.12 (1.0)				1.79				
2.24 (2.0)				1.38				
4.48 (4.0)				.82				
8.96 (8.0)				.13				
Simazine 1.12 (1.0) & Linuron .56 (.5)	2.49	1.78	1.36					
" 1.12 (1.0)	1.49	1.41	.92					
" 2.24 (2.0)	2.14	1.66	1.21					
" 4.48 (4.0)	1.30	1.73	.33					
"								
Simazine 3.36 (3.0) & Glyphosate 1.12 (1.0)				2.21				
2.24 (2.0)				2.15				
Simazine 1.12 (1.0) & Terbacil .28 (.25)	2.48	1.95	1.69					
.56 (.50)	2.40	1.57	1.60					
1.12 (1.00)	2.19	1.79	1.46					
2.24 (2.0)	2.52	2.12	1.67					
4.48 (4.0)	2.52	2.08	1.73					

Treatment Chemical Rate (kg/ha (lb/ac))						Gren-ville 34A (1978)	Grenville 34B (1978)		
		Grenville 7d(3) (1977)			Domtar 11('78)				
		DN22	DN1	JAC4	145/51	DN2	DN74	DTAC1	DN16
Terbacil	.28 (.25)						1.09	1.28	1.19
	.56 (.50)						.97	.83	1.08
	1.12 (1.00)						.78	.87	.94
	2.24 (2.00)						.71	.69	.65
	4.48 (4.00)						1.08	1.27	1.46
Sutylate 8.96 (8.0 & Diphenamide	.56 (.5)				1.00				
	1.12 (1.0)				1.07				
	2.24 (2.0)				.41				
	4.48 (4.0)				1.62				
	8.96 (8.0)				1.32				

APPENDIX 5

Standard Volume and Biomass Weight Tables for Clones 'DN 17' and 'I-45/51' in Eastern Ontario

Whole tree green weight (excluding leaves) for clone 'DN 17' (in kg)*

Diameter (cm at 1.3 m)	Total Tree Height (m) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.172	0.291	0.397	0.494											
3		1.554	2.117	2.635	3.124	3.589									
5			4.610	5.740	6.804	7.819	8.793	9.735	10.649						
7				9.586	11.363	13.057	14.684	16.257	17.783	19.270	20.868				
9						19.150	21.537	23.843	26.082	28.263	30.392	32.745			
11						26.001	29.241	32.373	35.413	38.373	41.264	44.093			
13								41.759	45.681	49.499	53.228	56.877	60.454	63.966	
15								51.936	56.813	61.562	66.199	70.737	75.186	79.554	
17										74.500	80.111	85.603	90.987	96.263	101.469
19										88.261	94.910	101.416	107.794	114.056	120.213
21											110.548	118.127	125.556	132.850	140.021
23											126.988	135.693	144.227	307.364	160.844
25												154.080	163.770	173.284	182.638

* Values for whole tree, excluding leaves (green weight in kg).
Block indicates extent of basic data (37 trees).
Tabular values derived from regression: weight (kg)= 0.993 X 0.762
where $X = D^2H$(in '000 cm)
$r^2 = 0.986$

Whole tree green weight (excluding leaves) for clone '1-45/51'*

Diameter	Total Tree Height (m)														
(cm at 1.3m)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.103	0.181	0.251	0.317											
3		1.077	1.498	1.893	2.269	2.632									
5			3.437	4.343	5.207	6.039	6.845								
7			5.940	7.506	8.998	10.436	11.830	13.186	14.511						
9				11.294	13.541	15.704	17.801	19.842	21.836	23.789					
11						21.763	24.669	27.497	30.261	32.967	35.623	38.234	40.805		
13						28.555	32.368	36.080	39.705	43.256	46.741	50.168	53.541		
15							40.848	45.532	50.107	54.588	58.987	63.310	67.567	71.763	
17							50.067	55.808	61.417	66.909	72.300	77.600	82.818	87.961	
19								66.872	73.592	80.173	86.633	92.983	99.235	105.398	111.479
21								78.690	86.597	94.342	101.943	109.416	116.773	124.024	131.180
23									100.403	109.382	118.195	26.859	135.389	143.796	152.093
25									114.981	125.264	135.357	145.278	155.047	164.676	174.176

* Values for whole tree, excluding leaves (green weight in kg).
Block indicates extent of basic data (37 trees).
Tabular values derived from regression: Weight (kg) = 0.668 X 0.813
where $X = D^2H$ (in '000 cm^3) $r^2 = 0.989$

Total cubic metre volume outside bark, for clone 'DN 17'.*

Diameter	Total Tree Height (m)														
(cm at 1.3m)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1		0.001	0.001	0.001	0.001	0.001									
3		0.001	0.002	0.002	0.002	0.003	0.003								
5			0.003	0.004	0.005	0.005	0.006	0.007							
7				0.007	0.008	0.009	0.011	0.012	0.014						
9				0.010	0.013	0.015	0.017	0.020	0.022	0.024					
11					0.018	0.022	0.026	0.029	0.033	0.036					
13					0.025	0.030	0.035	0.040	0.045	0.050	0.055	0.060			
15						0.040	0.047	0.053	0.060	0.066	0.073	0.079	0.086		
17						0.051	0.060	0.068	0.076	0.085	0.093	0.102	0.110	0.118	0.127
19							0.074	0.085	0.095	0.106	0.116	0.127	0.137	0.148	0.158
21							0.090	0.103	0.116	0.129	0.142	0.154	0.167	0.180	0.193
23								0.124	0.139	0.154	0.170	0.185	0.200	0.216	0.231
25									0.164	0.182	0.200	0.218	0.237	0.255	0.273

---

* Values for entire stem (ground to tip,) outside bark.
Block indicates extent of basic data (37 trees).
Tabular values derived from regression $V(cm^3) = 945.214 + 0.290X$,
where $X = D^2H$ (in cm) $r^2 = 0.969$.

Total cubic metre volume outside bark for clone 'I-45/51' *

Diameter	Total Tree Height (m)														
(cm at 1.3m)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.001	0.001	0.001	0.001											
3		0.002	0.002	0.002	0.002										
5		0.003	0.003	0.004	0.004	0.005	0.006								
7		0.004	0.005	0.007	0.008	0.009	0.011	0.012	0.013						
9			0.008	0.010	0.012	0.015	0.017	0.019	0.021	0.024					
11				0.015	0.018	0.021	0.025	0.028	0.031	0.035	0.038				
13						0.029	0.034	0.038	0.043	0.048	0.052	0.056			
15							0.045	0.051	0.057	0.063	0.069	0.075	0.082	0.087	0.093
17								0.065	0.073	0.081	0.089	0.097	0.105	0.112	0.120
19											0.110	0.120	0.130	0.140	0.150
21												0.147	0.159	0.171	0.183
23													0.190	0.205	0.219
25														0.242	0.259

* Values for entire stem (ground to tip) outside bark.

Block indicates extent of basic data (37 trees).

Tabular values derived from regression $V(cm^3) = 1245.413 + 0.275 X$,
where $X = D^2H$ (in cm) $r^2 = 0.965$

APPENDIX 6

Input Costs for Establishing Hybrid Poplar Plantations in Eastern Ontario, Based on Ontario Ministry of Natural Resources Data

Year 0 site preparation using the EPTC prescription is common to all management systems for year 0.

	Cost/hectare
Soil survey	$ 37.50
Brush cut	62.50
Ploughing	45.00
Discing (twice)	40.00
Cultivate	40.00
EPTC at 8.9 kg/ha*	
Chemical cost	150.00
Incorporation	25.00
Simazine at 3.9 kg/ha	
Chemical cost	33.75
Application	25.00

Management System 35K

Year 1 Planting	
Field planting costs	2,020.00
Stock cost at $25.00/1000	937.50
Total cost	$2,957.50
Year 2 No costs	
Year 3 Harvest 1	
Year 4 Glyphosate at 2.2 kg/ha	
Chemical cost	$ 125.00
Application cost	87.50
Total cost	$ 212.50
Fertilizer 8-32-16 at 68.1 kg/ha	
Application	$ 17.50
Fertilizer	75.00
Total cost	$ 92.50
Year 5 Harvest 2	
Year 6 Fertilize	$ 92.50
Year 7 Harvest 3	
Year 8 Fertilize	$ 92.50
Year 9 Harvest 4 etc.	

* Chemical rates are given as kg of active ingredient per ha.

Management System 4K

Year 1	Field planting costs	$ 175.00
	Stock costs	162.50
	Total cost	$ 337.50
Year 2	Glyphosate at 2.2 kg/ha	
	Linuron at 2.2 kg/ha	
	Chemical costs	$ 187.50
	Application costs	87.50
	Total cost	$ 275.00

Year 3 to 4 - no costs

Year 5 Harvest 1

Year 10 Harvest 2

Year 15 Harvest 3

etc.

Management System 1K

Year 1	Planting	
	Field planting costs	$ 62.50
	Stock costs	48.75
	Total cost	$ 111.25
Year 2	Glyphosate at 2.2 kg/ha Plus linuron at 2.2 kg/ha	$ 275.00

Year 3 - 9 No costs

Year 10 Harvest 1

Year 20 Harvest 2

Year 30 Harvest 3

etc.

(Data supplied by: W.E. Raitanen,
Regional Forestry Specialist,
Fast Growing Hardwoods Program,
O.M.N.R., Brockville, Ontario.)

APPENDIX 7

Estimated Input Costs for Establishing Hybrid Poplar Plantations in Eastern Ontario Based on Local Agricultural Costs

Site Preparation - using the EPTC Prescription is Common to all management systems for year 0.

Year 0

Operations	Cost/hectare
Soil survey	$ 37.50
Brush cutting	62.50
Ploughing	30.13
Discing (twice)	34.00
Cultivating	11.15
Incorporate EPTC spraying	10.97
discing (twice)	34.00
Applying simazine	10.97
Materials	
EPTC at 8.9 kg/ha	72.30
Simazine at 3.9 kg/ha	46.08
	$349.60

Management System 35K

Year 1

Operations	
Planting at 35,000/hectare	2,020.00
Materials	
Planting stock	926.50
	$2,946.50

Year 2 - no costs

Year 3 Harvest I

Year 4

Operations	
Fertilizer application granular 8-32-16 68.1 kg/ha	5.33
Anhydrous N 54.4 kg/ha	16.50
Applying glyphosate	10.98
Materials	
Fertilizer - Granular 8-32-16 at 68.1 kg	46.87
Fertilizer - Anyhdrous N 54.4 kg	47.50
Glyphosate at 2.2 kg/ha	123.18
	$250.36

Year 5 Harvest 2	
Year 6 Fertilizer	
Year 7 Harvest 3	
Year 8 Fertilizer etc.	116.40

Management System 4K

Year 1	
Planting at 4000/hectare	175.00
Planting stock cost	100.00
	$275.00
Year 2	
Glyphosate at 2.2 kg/ha Linuron at 2.2 kg/ha	229.62
Year 5 Harvest in Fall	
Year 10 Harvest in Fall	
Year 15 Harvest in Fall etc.	

Management System 1K

Year 1	
Planting at 1000/hectare	62.50
Planting stock	25.00
	$87.50
Year 2	
Glyphosate at 2.2 kg/ha Linuron at 2.2 kg/ha	229.62
Year 10 Harvest in Fall	
Year 20 Harvest in Fall	
Year 30 Harvest in Fall etc.	

APPENDIX 8

Common and Scientific Names of Trees and Shrubs

Ash	*Fraxinus* spp. L.
Autumn olive	*Elaeagnus umbellata* Thunb.
Balsam poplar	*P. balsamifera* L.
Birch	*Betula* spp. L.
Black gum	*Nyssa* spp. L.
Black locust	*Robinia pseudoacacia* L.
Black poplar	*P. Nigra* L.
Buffaloberry	*Shepherdia argentia* (Pursh)
Catalpa	*Catalpa* spp. Scop.
Chestnut	*Castanea* spp. Mill.
Eastern cottonwood	*Populus deltoides* Bartr.
Elm	*Ulmus* spp. L.
Empress-tree	*Poulownia* spp. Sieb. & Zucc.
European black alder	*Alnus glutinosa* (L.) Gaertn.
Hickory	*Carya* spp. Nutt.
Honey locust	*Gleditsia triacanthos* L.
Largetooth aspen	*Populus grandidentata* Michx.
Lespedeza	*Lespedeza* spp. Michx.
Red alder	*Alnus rubra* Bong.
Russian-olive	*Elaeagnus angustifolia* L.
Sassafras	*Sassafras* spp. T.F.L. Nees & Eberm.
Siberian peashrub	*Caragana arborescens* Lam.
Speckled alder	*Alnus rugosa* (Du Roi) Spreng.
Sweetgum	*Liquidambar* spp. L.
Tree-of-heaven	*Ailanthus* spp. Mill.
Trembling aspen	*Populus tremuloides* Michx.
Tulip tree	*Liriodendron* spp. L.
White poplar	*Populus alba* L.
Willow	*Salix* spp. L.

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POOR

QUALITY

ORIGINAL